# SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

## *Special Features*

1956 Literature Review, Part II—Research Committee

Industrial Wastes—Radioactivity

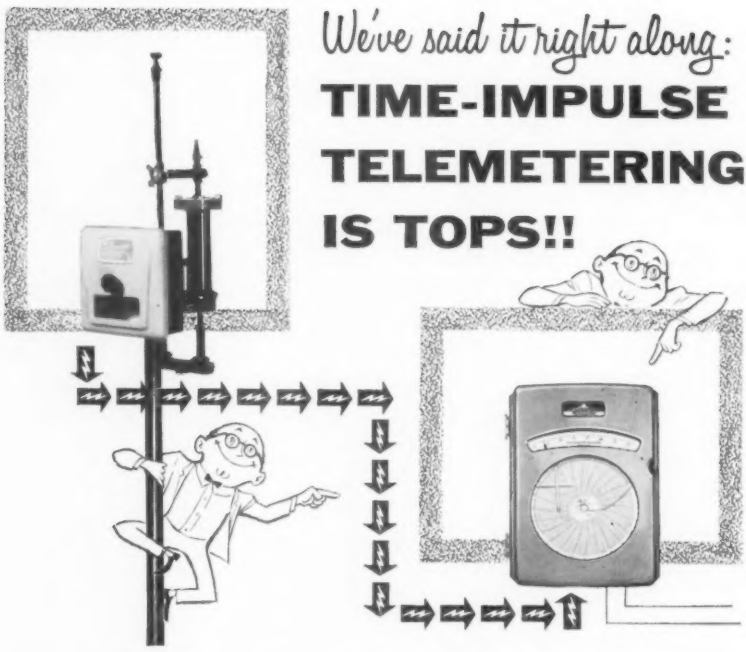
Combined Treatment Practices—ORSANCO

Syndets Review—McKinney

State Radioactive Waste Problems—Jensen et al.

Toxicity of Pure Chemicals—Wallen et al.

JUNE, 1957—VOL. 29, No. 6



*We've said it right along:*

# TIME-IMPULSE TELEMETERING IS TOPS!!

**...AND YOU'VE SAID IT TOO...WITH YOUR ORDERS!!**

**In Builders Chronoflo Telemetering Systems:** The transmitting and receiving reactions depend only upon the *positively* controlled duration of regular electric circuit closures and *nothing* more.

*The Telemeter is a pure, *positive-action* positioning system.

- It *does not* have to *translate* units of electric measurement into terms of rate of flow or other factors measured.
- It requires *no* relatively delicate electric components.
- It *doesn't employ* a series of contact rods "shorted out" by step-by-step action of rising mercury.
- It is *not affected* by normally encountered induced voltages.
- Receiver *accuracy not affected* by room temperature, line pressure, duration of "down time", and similar factors.

*The Chronoflo Receiver is *not* inferentially positioned except with respect to time duration of the Transmitter signals.

These are *only a few* reasons why time-impulse telemetering is "Tops". Let the company which pioneered this system over 25 years ago and has the experience gained in engineering thousands of installations give you complete proof of its dependability and accuracy.

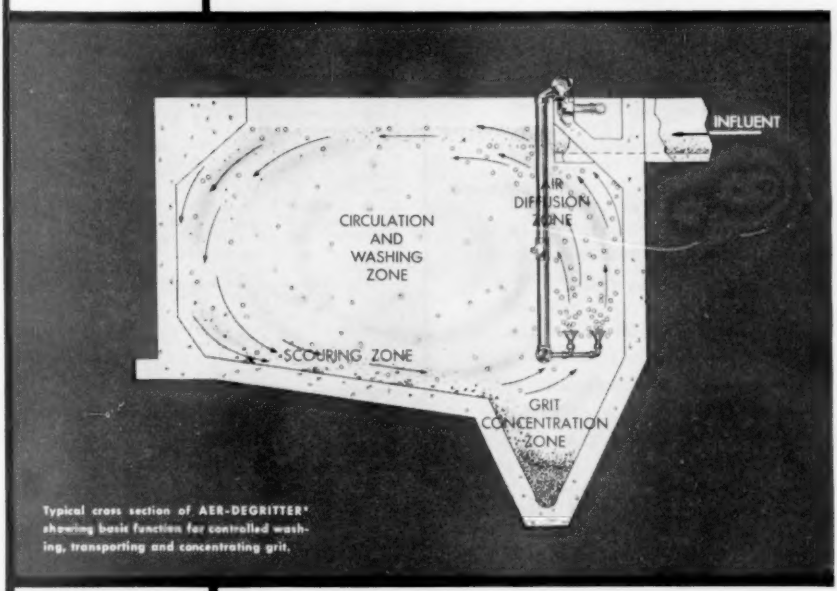
**Request Bulletin 230-H4A. Write Builders-Providence, Inc., 368 Harris Ave., Providence 1, R. I.**

BUILDERS-PROVIDENCE
DIVISION OF
B-I-F INDUSTRIES
METERS RECORDERS CONTROLS

"from Chicago"

**The WHY and HOW of SUCCESSFUL AERATED GRIT REMOVAL**

**Through the *AER-DEGRITTER** Grit Removal System**




Typical cross section of AER-DEGRITTER* showing basic function for controlled washing, transporting and concentrating grit.

**EXCLUSIVELY SUCCESSFUL COMBINATION of tank design and air diffuser location provides simultaneous grit washing and concentration, based upon:**

- ADEQUATE AIR DIFFUSION for controlled circulating velocities.
- CORRECT LOCATION OF AIR DIFFUSERS (unobstructed) directly over the hopper causes complete circulation of tank contents for grit washing and transporting across entire tank bottom into grit hopper. (Air diffusers in wrong location will "short circuit" bottom circulating velocities and cause uncontrolled grit and organic pile-up on tank bottom.)

Grit removal from tank hopper by Chicago Pump Company Air Lift pumps, tubular conveyors, screw or bucket elevators, clam-shell buckets or other means depending on specific job needs.

The AER-DEGRITTER* Aerated grit removal system is provided with Chicago Pump Company Swing Diffuser aeration equipment and, depending on requirements, Precision or FLEXOFUSER® diffusion tubes or Discfuser air nozzles.

**ONLY THE AER-DEGRITTER HAS A PROVEN RECORD OF SERVICE . . . OVER 150 INSTALLATIONS**

*The application of the equipment, as well as the equipment itself is covered by U.S. Patents No. 2,532,457, No. 2,328,655, No. 2,555,201 and pending patent applications.

always specify "Chicago"

**CHICAGO PUMP COMPANY**

*Sewage and Industrial Waste Equipment*

*Subsidiary of Food Machinery & Chemical Corporation*

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A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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Some sections of St. Petersburg's new sewer line were laid in deep trenches averaging 16 to 25 ft. Porous sands and mucky soil encountered made excavation almost impossible without the use of well points and pumps.

## St. Petersburg, Florida extends its sewer system with reinforced CONCRETE PIPE

St. Petersburg is engaged in the most comprehensive sanitary sewer construction program in its history. An initial $14,000,000 project will extend service from 8.4 to 50 sq. miles within the city limits. Future expansion will take place as population and commercial development increase.

The program includes many miles of concrete trunk lines and laterals, four treatment plants and 15 lift stations as well as major manhole installations and related facilities.

Like St. Petersburg, hundreds of cities have ***low-annual-cost*** concrete pipe sewer service. Some cities have had this service for 100 years and more.

Concrete pipe has a long, successful record because it offers (1) the strength to resist severe impact and to sustain heavy overburdens, (2) maximum hydraulic capacity and resistance to abrasion due to smooth interior surface and even joints and (3) tight joints and uniformly dense structure to insure minimum infiltration and leakage.

Concrete pipe sewers are moderate in first cost, need little or no maintenance and serve for years. They deliver ***low-annual-cost*** service, which benefits both civic officials and taxpayers.

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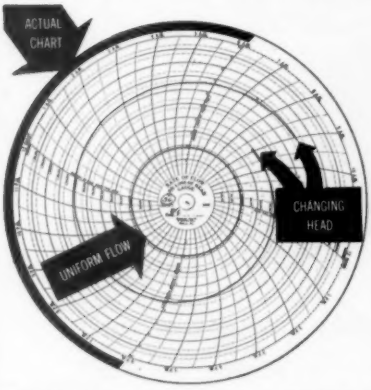
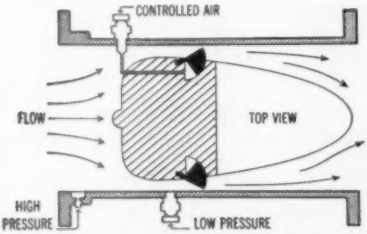
# NEW SIMPLEX MODULAIR HAS ONLY ONE MOVING PART...CONTROLS FLOW PRECISELY!

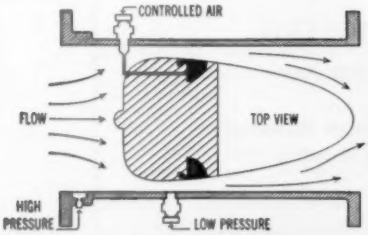
## Modulair® Controller regulates plant discharges, controls elutriation...responds fast...closes tight!



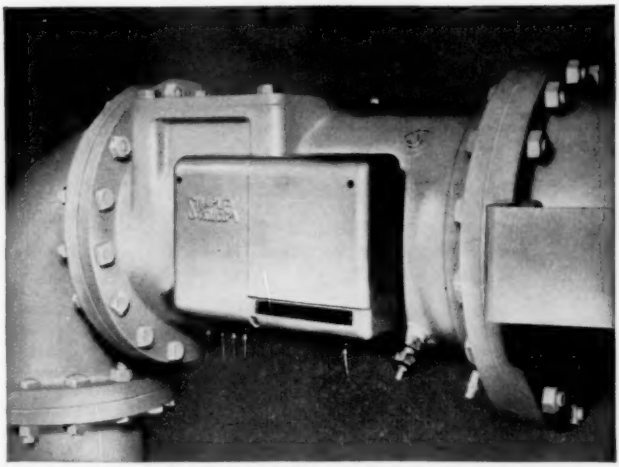

**Here's proof** that the new Simplex Modulair Controller responds instantly to changes in operating head . . . automatically holds flow at desired rate. Chart from Modulair installation shows head increasing 75% while flow forms almost perfect circle.




**How Modulair works!** Pipe-like casting with annular Venturi throat houses streamlined inner body with corded-rubber modulator (black) that expands and contracts pneumatically to control flow. When operating head rises, modulator expands automatically to restrict flow to set rate.




**When operating head falls,** flow tends to decrease—changing the Venturi differential. Sensitive Modulair compensates immediately. Modulator contracts—automatically keeps flow at rate desired.



**Compact . . . easily installed Modulair** is only 2 to 3 pipe diameters long! Fits wherever a piece of pipe can fit . . . in any position, horizontal or vertical—simplifying piping layout. Modulair comes in 4" to 24" cast iron pipe sizes with corrosion-resisting fittings. Corded-rubber throttling element that's as tough as a truck tire has given 30 years' wear in accelerated life-tests.

**Accuracy!** In 4 years of field performance, Modulair shows an accuracy in control that exceeds today's most exacting demands. It brings you sensitive, accurate flow control under wide ranges of operating head. And is tight-closing—eliminating need for separate shut-off valves.

**Minimize maintenance!** With Modulair's single tap design, there's no place for air to accumulate . . . no place for sediment or sludge to lodge and interfere with accuracy. The only moving part inside pipeline is non-corrosive rubber throttling element. Pneumatic poise element is simple, rugged. There are no line valves, no pilot valves, no pistons, no valve shafts, no stuffing boxes to pack!

**Lower first cost.** Modulair's low head loss means lower operating-head requirements . . . permits vertical compression in plant design and lower costs in plant construction.

**Completely pneumatic!** No intermediate hydraulic steps! No pilot valves! No hydraulic cylinders! Air loading pressure is applied *directly* to the flow controlling element.

**Automatic operation!** Modulair works with control systems of any type to give you remote rate control or master pneumatic control that's fully automatic.

**Technical bulletin!** Write for Bulletin 950. Simplex Valve & Meter Company, Dept.SI-6, 7 East Orange Street, Lancaster, Pa.

Accurate instruments and controls for over 50 years

**SIMPLEX®**

VALVE AND METER COMPANY

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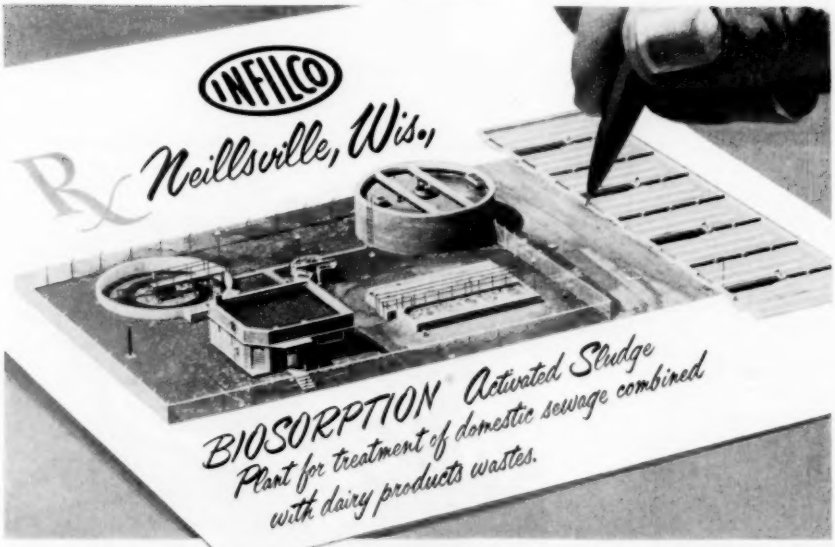
| *Association* | *Place* | *Time* |
|---|---|---|
| Alabama Water and Sewage Assn. | University of Alabama<br>University, Ala. | June 3–5, 1957 |
| New England Sewage and Industrial Wastes Assn. | Viking Hotel<br>Newport, R. I. | June 6, 1957 |
| New York Sewage and Industrial Wastes Assn. | Whiteface Inn<br>Lake Placid, N. Y. | June 17–18, 1957 |
| Iowa Sewage and Industrial Wastes Assn. | Hotel Kirkwood<br>Des Moines, Iowa | June 19–21, 1957 |
| Ohio Sewage and Industrial Wastes Treatment Conf. | Miami Hotel<br>Dayton, Ohio | June 19–21, 1957 |
| Institute of Sewage Purification | Margate, England | June 25–28, 1957 |
| Central States Sewage and Industrial Wastes Assn. | Sherman Hotel<br>Chicago, Ill. | June 26–28, 1957 |
| Pennsylvania Sewage and Industrial Wastes Assn. | Pennsylvania State College<br>University Park, Pa. | Aug. 28–30, 1957 |
| South Dakota Water and Sewage Works Conf. | Sheraton Cataract Hotel<br>Sioux Falls, So. Dak. | Sept. 11–13, 1957 |
| Kentucky-Tennessee Industrial Wastes and Sewage Works Assn. | Brown Hotel<br>Louisville, Ky. | Sept. 23–25, 1957 |
| Rocky Mountain Sewage and Industrial Wastes Assn. | LaFonda Hotel<br>Santa Fe, N. Mex. | Sept. 23, 1957 |
| Oklahoma Water, Sewage and Industrial Wastes Conf. (Ind. Wastes) | A. & M. College<br>Stillwater, Okla. | Sept. 25–26, 1957 |
| North Dakota Water and Sewage Works Conf. | Gardner Hotel<br>Fargo, No. Dak. | Sept. 25–27, 1957 |
| Georgia Water and Sewage Assn. | Georgia Inst. of Technology<br>Atlanta, Ga. | Sept. 25–27, 1957 |

### THIRTIETH ANNUAL MEETING

**Federation of Sewage and Industrial Wastes Associations**
**in conjunction with**
**New England Sewage and Industrial Wastes Association**
**Statler Hotel, Boston, Massachusetts**
**October 7–10, 1957**




## B.O.D. removal in half the space and half the time!

Efficient, **high-rate** "BIOSORPTION" plant installed at Neillsville. Consulting Engineers — Davy Engineering Co., La Crosse, Wis.

**The PROBLEM:** To provide 80% B.O.D. removal from domestic sewage and milk plant wastes combined as follows:

| | G.P.D | POP. EQUIV. | B.O.D. lbs. |
|---|---|---|---|
| Domestic sewage | 278,000 | 3132 | 522 |
| Milk plant #1 | 24,400 | 2658 | 443 |
| Milk plant #2 | 39,800 | 2052 | 342 |
| | 342,200 | 7842 | 1307 |

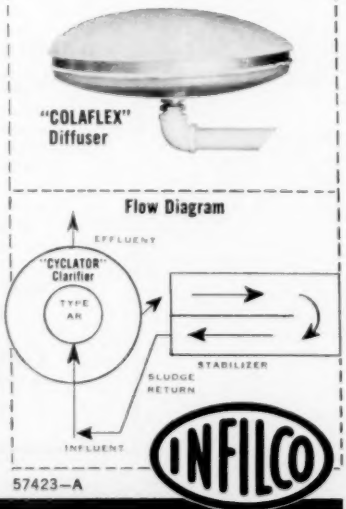
**The SOLUTION:** The "BIOSORPTION" activated sludge plant illustrated above was installed for maximum capacity in minimum space — highest efficiency at lowest cost. Equipment includes a CYCLATOR® clarifier combining mixing and clarification in a *single* basin; Stabilizer with 120 COLAFLEX® diffusers; GRIDUCTOR® comminutor, and digester.

**The RESULTS:** Typical hourly samples composited for analysis:

| 1956 Date | Time | Ave. Flow M.G.D. | B.O.D. Raw Sewage P.P.M. | B.O.D. Percent Removal | Sus. Solids Raw Sewage P.P.M. | Sus. Solids Percent Removal |
|---|---|---|---|---|---|---|
| Nov. 21 | 9 A.M.-4 P.M. | 0.262 | 1330 | 80.9 | — | — |
| Nov. 27 | 8 A.M.-4 P.M. | 0.226 | 741 | 83.7 | 366 | 78.2 |
| Nov. 28 | 8 A.M.-4 P.M. | 0.248 | 794 | 88.4 | 480 | 83.3 |
| Dec. 3 | 8 A.M.-4 P.M. | 0.232 | 642 | 80.5 | 508 | 84.2 |

If your problem involves greater capacity in *less* time — from *less* space — *at lower cost* — consult INFILCO because INFILCO KNOWS HOW to help you solve it. Write today for full information on this installation and Bulletin No. 6550.

Inquiries and samples are invited on all water, sewage and waste treatment problems.

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THE ONLY COMPANY impartially offering equipment for ALL types of water and waste conditioning—coagulation, precipitation, sedimentation, flotation, filtration, ion exchange and biological treatment.

**burning water...**

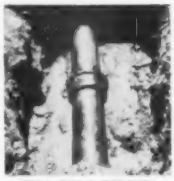
A carelessly flicked match or cigarette...

A forest dies. Water, no longer absorbed by the sunbaked soil, runs off... carries with it irreplaceable topsoil. Another natural watershed... life and health for thousands... is lost. Sometimes, for centuries!

You can help stop this criminal waste of God-given resources. In the woods, be careful of matches and campfires. As for water:

1. **Encourage future planning of water facilities.**
2. **Support realistic water rates and water supply bond issues.**
3. **Conserve water wherever you can.**

"Plentiful as water" no longer applies to America.



**STILL GOING STRONG!**

This 8" cast iron water main laid in Williamsport, Pennsylvania in 1855. Carrying water from the city's reservoir to its distribution system, it has been in continuous use for 102 years and is still in excellent condition.

Performance like this is another of the many reasons forward-looking water officials specify cast iron pipe. It's America's Number One Tax Saver... and the record proves it!

**CAST IRON PIPE**
RESEARCH ASSOCIATION — SUITE 2440, PRUDENTIAL PLAZA, CHICAGO 1, ILL.

MODERNIZED **cast iron**

# WATER...

# IS EVERYONE'S BUSINESS!

The sooner Americans realize the gravity of our water problem the better it will be for them . . . and for you.

No easy job convincing *your* community it can no longer take water for granted. But advertisements* like the one opposite help you.

Not only do they warn of the growing seriousness of our water problem; they tell Americans what to do about it.

This means more support, sympathy and cooperation for *your* program . . . big or small as it may be.

CAST IRON

Cast Iron Pipe Research Association, Thos. F. Wolfe,
Managing Director, Suite 3440, Prudential Plaza, Chicago 1, Ill.

**Appearing in:* Nation's Business, Newsweek,
Saturday Evening Post, U. S. News & World Report.

pipe FOR MODERN WATER WORKS

**CHAPMAN**

**Standard Sluice Gates**

Everything is standardized . . . all component parts. This applies to more than 300 types and sizes of Chapman Standard Sluice Gates. In this way, Chapman can meet *your* specifications at the lowest possible costs. These standardized parts are interchangeable. There's nothing hit or miss about the installation . . . no expensive matchmarking or field alterations. Everything is fitted perfectly at rock bottom cost. Even in use, these gates guard your dollars. The standardized parts are easy to replace . . . easy to fit. It's easy to keep your sluice gates in ideal working condition without expensive repair or service.

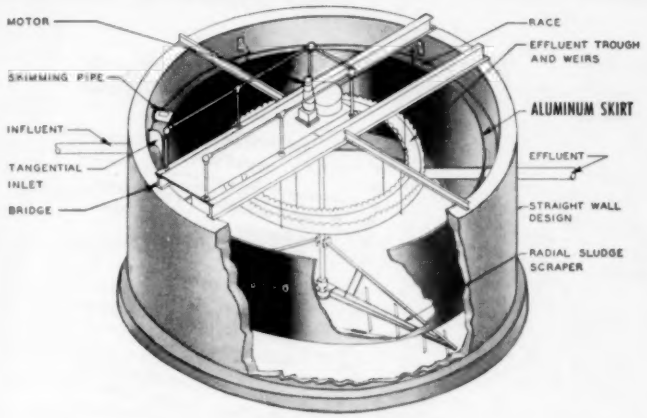
What's your requirement? Is it high or low head, seating or unseating pressures, large or small water area? Do you want manual, hydraulic or electric motor operation? Just name it. Chapman has the answer . . . sluice gates to meet your needs, standardized, every one.

Why not write for our Catalog 25-A, now?

**The CHAPMAN VALVE MANUFACTURING CO.**
INDIAN ORCHARD, MASS.

# YEOMANS SPIRAFLO CLARIFIER REMOVES MORE SOLIDS AND ELIMINATES SHORT CIRCUITING

***because of this skirt baffle***




## YEOMANS SPIRAFLO . . .

**for both primary and final clarification**

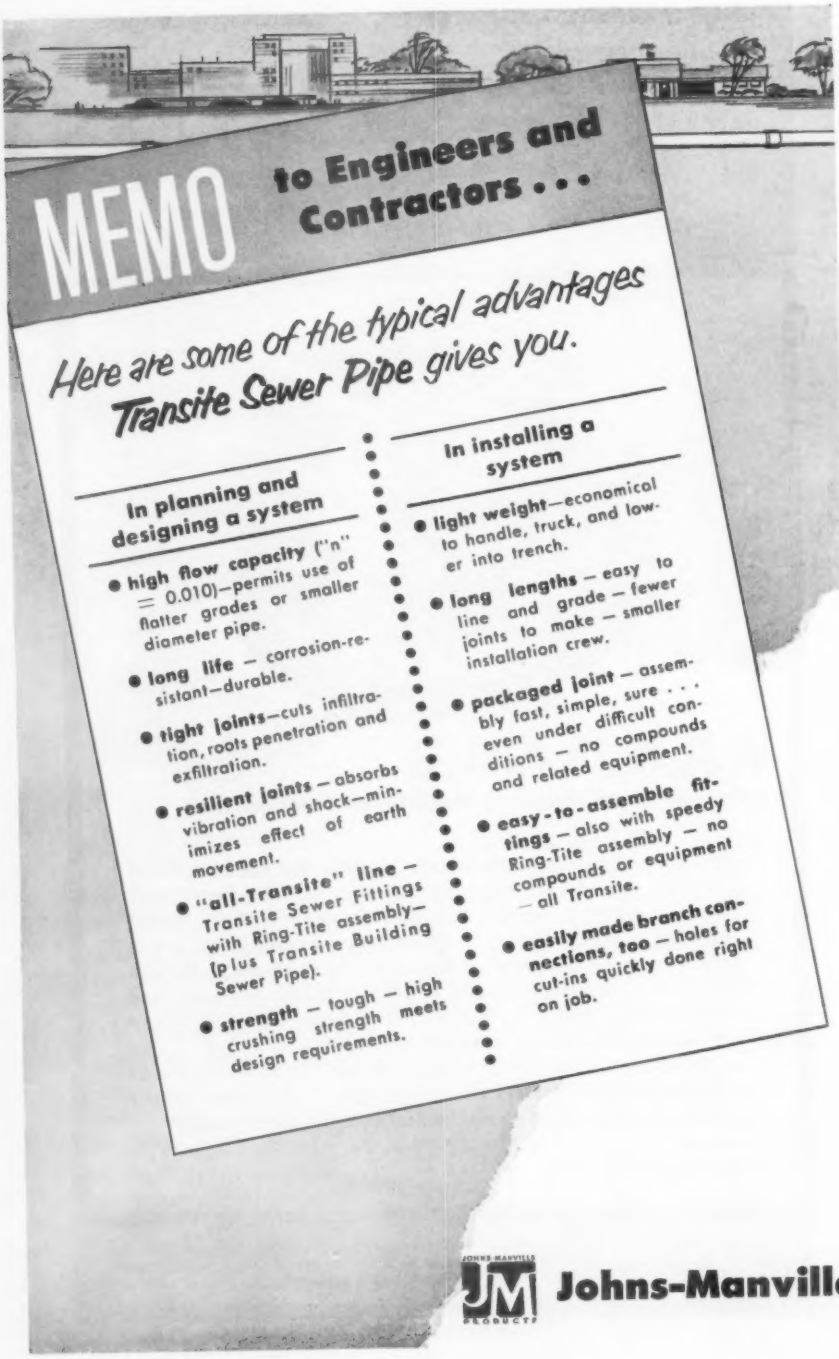
The aluminum skirt forms an annular race. Sewage introduced into this race spirals slowly down and enters the clarification compartment at the bottom. Diffusion is slow and uniform. Settleable solids are completely removed. Sewage moving upwards in the clarification compartment passes through a sludge zone. Here increased flocculation occurs. 70% Of the suspended solids and finely divided particles is removed. Oil, grease, and scum *remain* in the annular race and enter a skimming pipe.

And over-all construction costs are low. Why? Straight-wall design, without concrete effluent troughs . . . no underground piping for influent . . . no mechanical or hydraulic skimmers.

*For full information write:*

**YEOMANS** manufacturers of: distributors • clarifiers • digesters • mechanical aerators • pneumatic sewage ejectors • centrifugal pumps

**Yeomans • 1999-7 N. Ruby St., Melrose Park, Ill.**


MEMO to Engineers and Contractors . . .
Here are some of the typical advantages Transite Sewer Pipe gives you.
In planning and designing a system
● high flow capacity ("n" = 0.010)—permits use of flatter grades or smaller diameter pipe.
● long life — corrosion-resistant—durable.
● tight joints—cuts infiltration, roots penetration and exfiltration.
● resilient joints — absorbs vibration and shock—minimizes effect of earth movement.
● "all-Transite" line — Transite Sewer Fittings with Ring-Tite assembly—(plus Transite Building Sewer Pipe).
● strength — tough — high crushing strength meets design requirements.
In installing a system
● light weight—economical to handle, truck, and lower into trench.
● long lengths — easy to line and grade — fewer joints to make — smaller installation crew.
● packaged joint — assembly fast, simple, sure . . . even under difficult conditions — no compounds and related equipment.
● easy-to-assemble fittings — also with speedy Ring-Tite assembly — no compounds or equipment — all Transite.
● easily made branch connections, too — holes for cut-ins quickly done right on job.
JM
Johns-Manville

## *Select*

**Transite® for more economical, tighter sewerage systems . . .**

WHETHER a new sewerage system is being planned or additions to an existing one are being made . . . engineer and contractor alike will find a combination of qualities in performance-proved Transite Sewer Pipe that will fit their individual needs. They will find this holds true whether the local conditions call for (a) tight joints to protect against root growth and infiltration of ground water or (b) the strength and flow characteristics that mean definite savings in the design stage, during trenching and installation, and in operation as well.

For further information about Transite Sewer Pipe, write for Booklet TR-165A, Johns-Manville, Box 14, N. Y. 16, N. Y.

**TRANSITE SEWER PIPE**
**with the RING-TITE® Coupling**

We have prepared, in conjunction with various testing companies, a series of factual, technical reports on the subject of waterstops. These Technical Reports cover the many aspects of adequate concrete joint design and should prove to be a valuable addition to your design files. Although these reports are strictly technical information and not sales catalogs, they conclusively prove that DURAJOINT and DURASEAL PVC Waterstops are the only waterstops on the market that will produce a practically 100% watertight joint. Check the coupon below for your free copies of these Technical Reports. Why not mail it now while you are still thinking about it?

**DURAJOINT TECH-TIPS**

. . . a series of Technical Data Sheets that contain complete information on the design, handling, splicing, installation and structural recommendations on the application of DURAJOINT and DURASEAL Waterstops. Send coupon today for your free set of DURAJOINT "Tech-Tips."

**NATIONAL DISTRIBUTION**

"DURAJOINT" enjoys national distribution through the distributors of Tecon Inc. in the 11 western states and W. R. Meadows, Inc. in the 37 states of the mid-western, southern and eastern portions of the United States.

**DURAJOINT** TECHNICAL INFORMATION *Center*

121 HILL AVENUE · AURORA, ILLINOIS

**Please send me, without obligation, the following:** DEPT. 36

- ☐ **TECHNICAL REPORT NO. 1**... How Cross Section Design Affects Bonding to the Concrete.
- ☐ **TECHNICAL REPORT NO. 2**...Tests and Methods of Testing Polyvinylchloride Waterstops.
- ☐ **TECHNICAL REPORT NO. 3**...DURAJOINT Tests and Test Results by the U. S. Testing Company, Inc.
- ☐ **TECHNICAL REPORT NO. 4**... Hydrostatic Pressure Tests on DURAJOINT and other Waterstops.
- ☐ **DURAJOINT** "Tech-Tip" Series.
- ☐ Have representative call.

NAME_____

FIRM_____

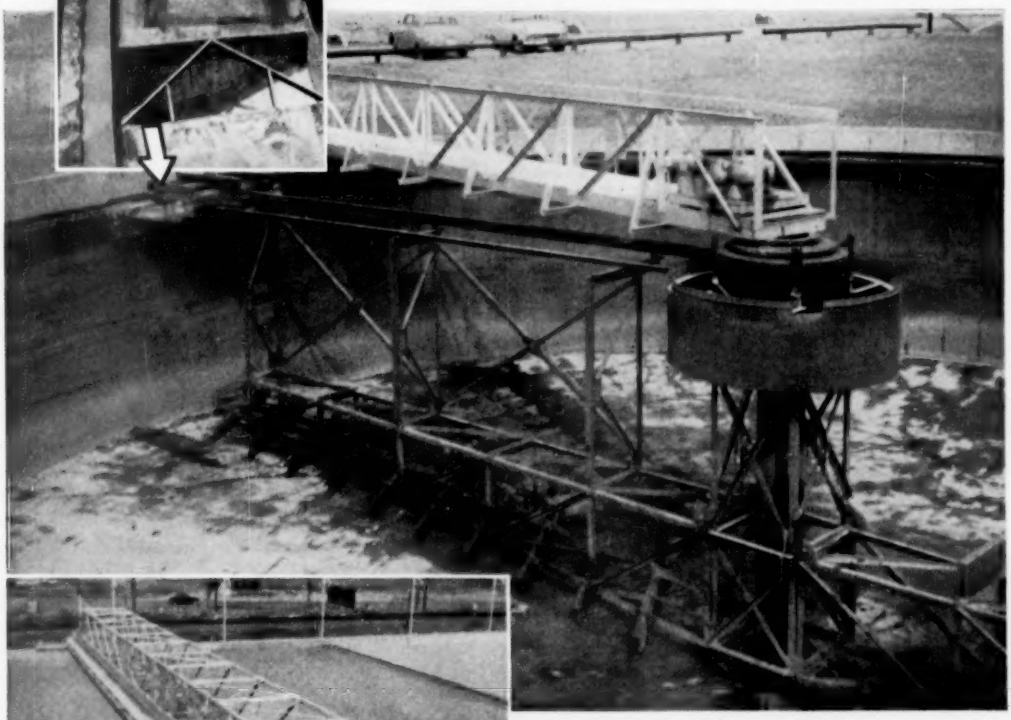
ADDRESS_____

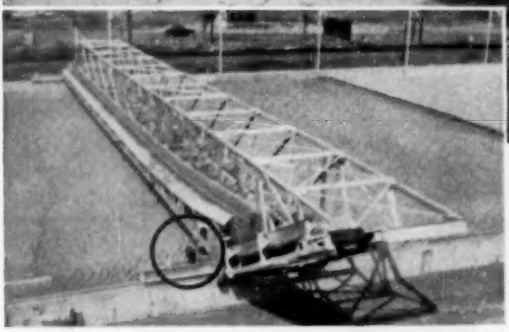
CITY_____ STATE_____

# LINK-BELT equipment helps bring Manhattan, Kansas

# low-cost sewage treatment

**70-FT. LINK-BELT CIRCULINE** Sludge Collector is fed raw sewage from bottom of tank. Specified by Wilson & Co., consultants, system features a superior automatic scum skimmer with rotating collection blade. Scum is worked into pocket by rotation. Passage of hinged blade on rotating arm (inset) deposits scum in box, eliminating all manual handling.





**TRAVELING BELT CONVEYOR** conveys dry sludge from 10 drying beds to trucks, thus reducing manual handling of sludge to a minimum. Push-button control station (circled) permits operator to move bridge automatically as removal progresses.

## Circuline sludge collectors with automatic scum skimmers and traveling belt conveyor mechanize sludge collection and disposal

Like so many municipalities and industrial plants, the city of Manhattan uses Link-Belt Circuline Collectors for quick, low-cost sludge and scum removal. This integrated system incorporates a traveling belt conveyor and automatic scum skimmers—provides efficient, positive sludge removal . . . minimizes manual handling.

Link-Belt can apply a complete line of sanitary engineering equipment and extensive experience to your water, sewage or industrial waste treatment problems . . . will gladly work with your chemists and consultants. Call your nearby Link-Belt office.

**LINK-BELT**

**SANITARY ENGINEERING EQUIPMENT**

**LINK-BELT COMPANY:** Executive Offices, Prudential Plaza, Chicago 1. To Serve Industry There Are Link-Belt Plants and Sales Offices in All Principal Cities. Export Office, New York 7; Canada, Scarboro (Toronto 13); Australia, Marrickville (Sydney), N.S.W.; South Africa, Springs. Representatives Throughout the World. 54,400

# slips on like

U.S. cast iron PIPE FOR WATER, SEWERAGE AND

# an old shoe

But once *in*, our revolutionary new "Tyton Joint" pipe seals bottle-tight. Hydrostatic tests on restrained "Tyton Joints" show that they will withstand pressures well in excess of hydrostatic test pressures required by the pipe specifications.

And only *one* accessory needed...a simple rubber gasket. This gasket fits into the bell end, and the connecting pipe compresses the gasket and seals the joint permanently. No bell holes. No delays. "Tyton Joint" pipe can be laid in rain or a wet trench. And even the newest crew can handle it.

Like full information on "Tyton Joint" pipe whose installation is simple, speedy and sure? Call or write us today and get the facts that will save you time, trouble, money in the trench.

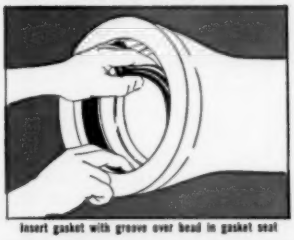
**U. S. PIPE AND FOUNDRY COMPANY**
**General Office: Birmingham 2, Alabama**

A WHOLLY INTEGRATED PRODUCER FROM MINES AND BLAST FURNACES TO FINISHED PIPE

**INDUSTRIAL SERVICE** CAST IRON

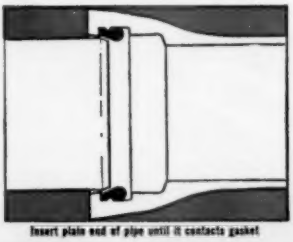
U. S. TYTON JOINT

**ONLY FOUR SIMPLE ACTIONS**

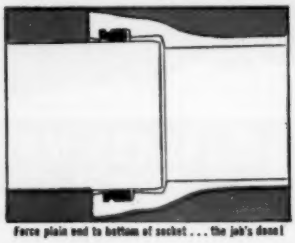


Insert gasket with groove over head in gasket seat

Wipe a film of special lubricant over inside of gasket



Insert plain end of pipe until it contacts gasket

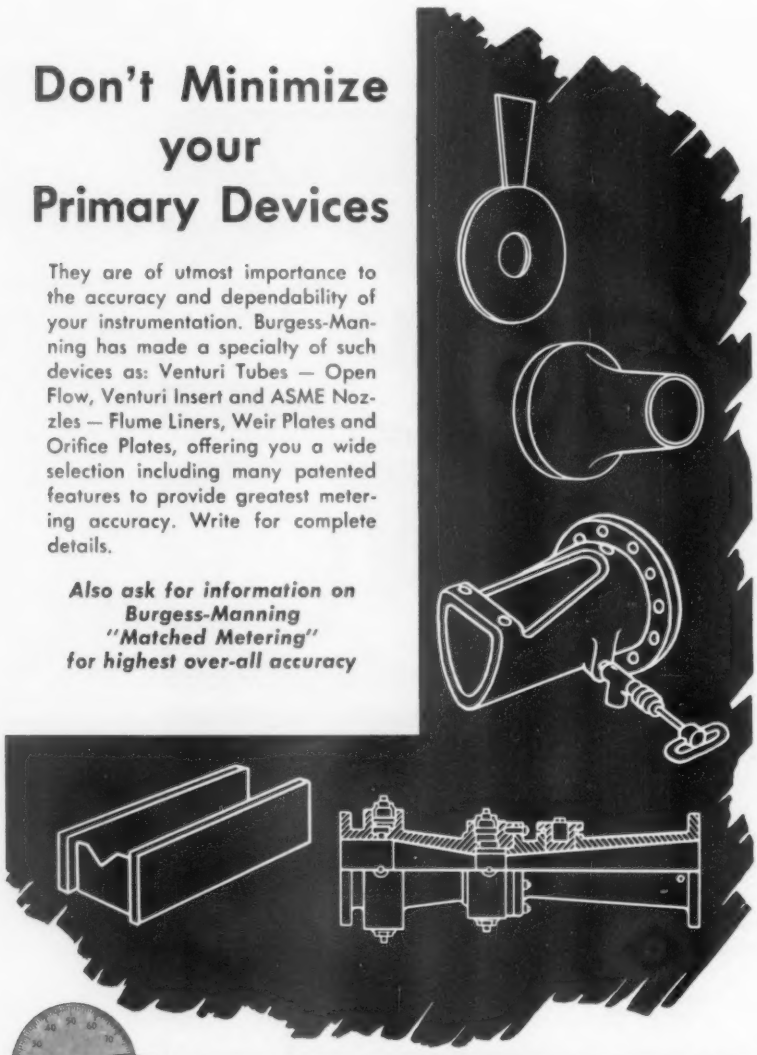


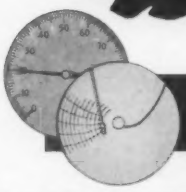
Force plain end to bottom of socket . . . the job's done!

# Don't Minimize your Primary Devices

They are of utmost importance to the accuracy and dependability of your instrumentation. Burgess-Manning has made a specialty of such devices as: Venturi Tubes — Open Flow, Venturi Insert and ASME Nozzles — Flume Liners, Weir Plates and Orifice Plates, offering you a wide selection including many patented features to provide greatest metering accuracy. Write for complete details.

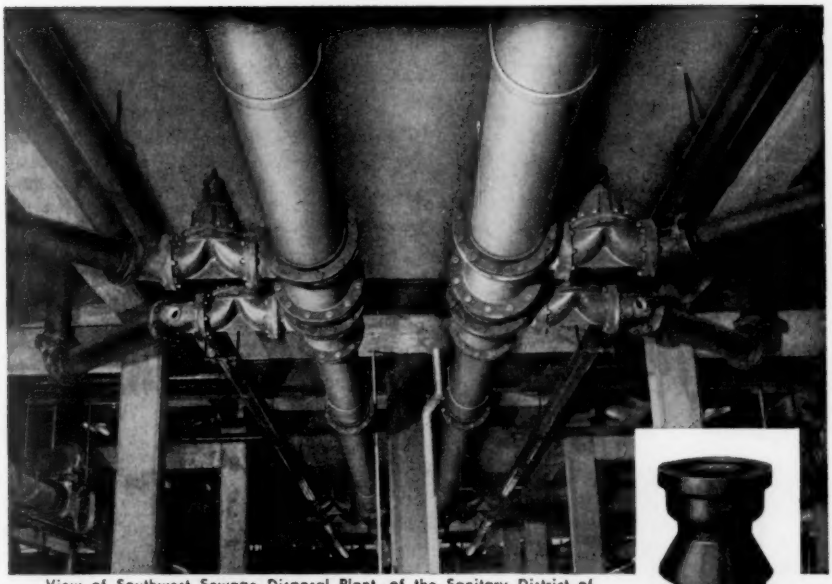
***Also ask for information on Burgess-Manning "Matched Metering" for highest over-all accuracy***





**BURGESS-MANNING COMPANY**
PENN INSTRUMENTS DIVISION
4122 Haverford Ave., Philadelphia 4, Pennsylvania

**Instrumentation and Controls for water, steam, gases, sewage and industrial wastes**



View of Southwest Sewage Disposal Plant, of the Sanitary District of Chicago, Stickney, Illinois . . where Clow Cast Iron Pipe was furnished to meet exact requirements.

# Clow cast iron pipe, fittings, valves and specials for sewage plant replacements or new installations

• James B. Clow & Sons with their many years of experience as manufacturers of Cast Iron Pipe and Special Castings for Filtration and Sewage Disposal Plants know the difficult piping problems that continually face the sanitary engineer. Clow shops are completely equipped with the latest machinery. Clow's skilled workmen will produce pipe and specials to your exact specifications. Pipe can be furnished flange and flange, flange and bell, flange and plain end or with mechanical joint and plain end—in sizes 3 through 24 inches in laying lengths up to 18 feet.

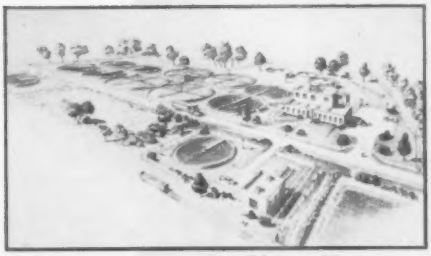
**CLOW (Threaded) Cast Iron Pipe**

Clow also manufactures (threaded) Cast Iron Pipe in steel pipe sizes 3 through 10 inches which has the same outside diameter as common steel pipe. This pipe can be cut, threaded and fitted on the job with ordinary tools of the piping trade.

**JAMES B. CLOW & SONS** ☆

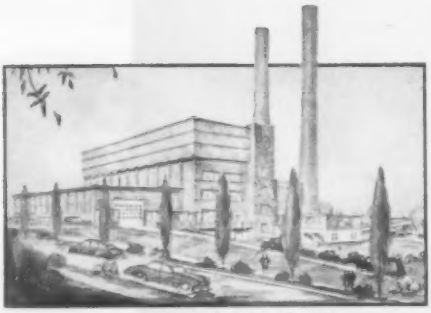
201-299 North Talman Avenue • Chicago 80, Illinois

Subsidiaries:
Eddy Valve Co., Waterford, N. Y.
Iowa Valve Co., Oskaloosa, Iowa



Lynchburg, Va.

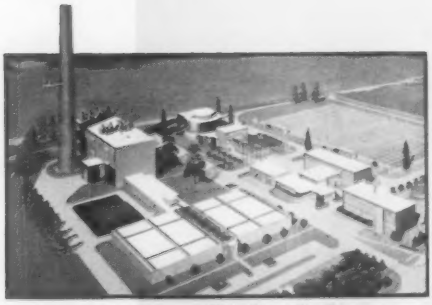
**Drying Sludge for Fertilizer** — The new sewage treatment plant at Lynchburg, Virginia, is designed for a population equivalent of 70,000. It will have a design flow of 11,000,000 gallons per day and will produce primary digested sludge. A C-E Raymond Flash Drying System, complete with storage bin and bagging equipment, will dry this sludge for use as a fertilizer. The flash drying equipment will evaporate 2,750 pounds of water per hour while producing 1,225 pounds of dry solids.
***Wiley & Wilson, Engineers.***



Louisville, Ky.

**Drying and/or Incinerating Sludge with Refuse**—The two C-E Raymond Flash Drying Systems to be installed in Louisville's new *refuse* disposal plant provide an economical and flexible sludge disposal facility. Sludge filter cake will be trucked from the sewage treatment plant to the refuse disposal plant. Utilizing the refuse incinerator's waste heat, the C-E Flash Drying Units dry the entire sludge output. It can then be sold as fertilizer or used on municipal golf courses, parks and lawns. Unused sludge can be incinerated with the City's refuse. The plant serves a population equivalent of about 500,000.
***Metcalf & Eddy, Engineers.***

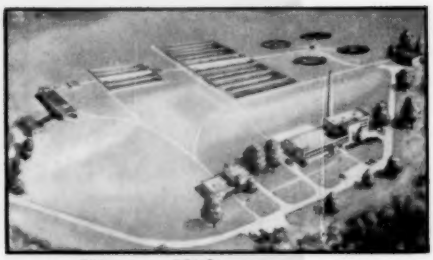
# THEY CHOSE C-E RAYMOND IN 1956



Pittsburgh, Pa.

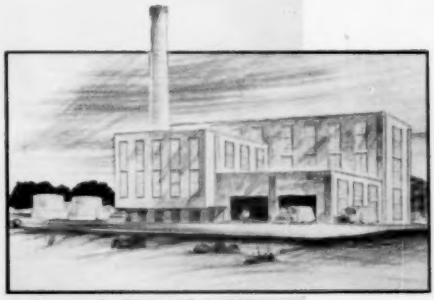
**Sewage Sludge Incineration** — This seventeen million dollar plant will serve seventy communities in the Pittsburgh area, having a population equivalent of 1,500,000. It will include four C-E Raymond Flash Drying and Incineration Systems capable of handling over 300 tons of concentrated sludge per day. They are designed to burn 55 tons of dry solids while evaporating more than 250 tons of water. Each unit will be equipped with a Deodorizing System to free all foul gases of objectionable odor. In addition, each unit will incorporate equipment for the control of fly ash.
***Metcalf & Eddy, Engineers.***

**Drying and/or Incinerating Sludge —**
This plant, designed to serve an equivalent population of 136,000 in the Warren area, will produce both activated and raw primary sludges. Three C-E Raymond Flash Drying Systems will dry and/or incinerate its entire output. Because of the heavy concentration of diversified industry in the Warren area, it is planned to use only one of the three C-E Raymond units to dry sludge for use as a soil conditioner. The remaining two units will be used for incineration, but can be quickly and easily converted to fertilizer production.
***Johnson & Anderson, Engineers.***



**Warren, Mich.**

**Disposal of All Municipal Wastes —**
This new plant will dispose of all municipal refuse from the cities of Neenah and Menasha, Wisconsin. Garbage, rubbish and refuse, and sewage sludge will be burned in two C-E Traveling Grate Refuse Incinerators. Heat from the incinerators will be used in a C-E Raymond Flash Drying System to dry the entire output of sludge from the sewage treatment plant. Once dry, it can be used for fertilizer, if desired, or returned to either or both of the incinerators and burned.
***McMahon Engineering Co., Engineers.***



**Neenah-Menasha, Wisc.**

The C-E Raymond Flash Drying and Incineration System for sewage sludge disposal is the most versatile and flexible system available. As evidenced by these brief descriptions of some 1956 contracts, the C-E Raymond Flash Drying System can be used to dry sludge for use as a soil conditioner, to incinerate it to a sterile ash, or both. It can be combined with existing refuse incinerators or installed integral with the C-E Traveling Grate Incinerator to take advantage of available waste heat resulting from the incineration of garbage and refuse. It can be equipped with its own heat source, burning either dry sludge or purchased fuel.

If you are considering new sewage disposal facilities — alone or in combination with refuse disposal, see C-E. We will be happy to discuss your needs with you and with your consultants.

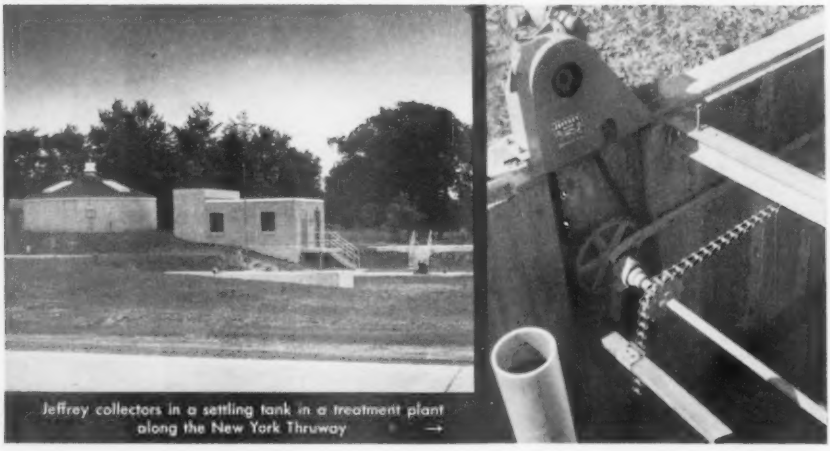
**COMBUSTION ENGINEERING**

B-994A

**RAYMOND DIVISION, 1315 North Branch Street, Chicago 22, Illinois**
**Eastern Office: 200 Madison Avenue, New York 16, N. Y.**
**Western Office: 510 West Sixth Street, Los Angeles 14, Cal.**
ALSO FLASH DRYING AND INCINERATION SYSTEMS FOR INDUSTRIAL WASTE DISPOSAL

# Superhighways

## introduce problems of sanitation...



Jeffrey collectors in a settling tank in a treatment plant along the New York Thruway →

**Jeffrey equipment is helping solve them**

IT'S SMALLER in size, of course, to meet the demands of these thruway service areas. But the Jeffrey Sanitation Equipment employed has the same high degree of dependability as that used in hundreds of sewage, water and industrial waste treatment plants all over the world.

Jeffrey engineers' broad experience in the design and construction of sanitation systems covers all kinds of treatment needs. You can turn your treatment problems over to them with complete confidence. Jeffrey equipment can be depended upon to perform well and faithfully.

Catalog 905 describes Jeffrey Sanitation Equipment. For a copy, write The Jeffrey Manufacturing Company, 902 North Fourth Street, Columbus 16, Ohio.

CONVEYING • PROCESSING • MINING EQUIPMENT . . . TRANSMISSION MACHINERY . . . CONTRACT MANUFACTURING

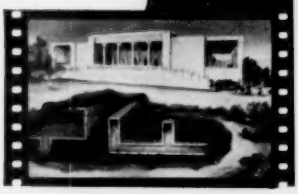
JEFFREY

This film, specially produced for the American Concrete Pressure Pipe Association, dramatizes the evolution of water supply systems down through the ages.

Professional actors and authentic sets appear in all the historical scenes.

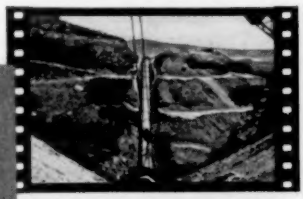
16 mm color prints of the film are available on loan for group showing. Two versions are available, one with a running time of approximately a half hour, the other, 20 minutes.

For information, write the American Concrete Pressure Pipe Association, 228 North LaSalle Street, Chicago 1, Illinois.



Water supply systems were constructed of stone and masonry nearly 6000 years ago by Persian engineers.

With the Dark Ages, advancements in water transportation were lost and water was supplied from communal wells.



Modern concrete pressure pipe carries water over long distances for homes, factories and farms.

**AMERICAN CONCRETE PRESSURE PIPE ASSOCIATION**

228 North LaSalle St.
Chicago 1, Illinois

Concrete PRESSURE Pipe

WATER FOR GENERATIONS TO COME

# LASTING PROTECTION ASSURED!

# INERTOL® PAINTS

**specified 100% for Linden—Roselle, N. J., Sewage Plant**

**Pumping station** of new $4,000,000 Linden—Roselle Sewage Treatment Plant. The entire plant is painted with Inertol coatings. Colorful Glamortex® quality alkyd, along with Ramuc® Utility Enamel and Ramuc Floor Enamel—both chlorinated natural rubber-base coatings in color—are but three of the Inertol paints chosen to attractively protect this plant.

Chemical fumes, high humidity, corrosive industrial wastes—such destructive influences had to be combated to maintain the plant's good looks and assure maintenance economy. Inertol coatings were specified exclusively by Consulting Engineer M. H. Klegerman of Alexander Potter Associates, New York, N. Y.

Throughout this plant Inertol colored enamels and bituminous coatings are at work. They not only provide top, trouble-free service, but their hardness, chemical inertness and elasticity mean safe, efficient, low-cost protection as well.

Thousands of installations all over the country enjoy Inertol protection and beauty. Your plant can benefit, too. Buy Inertol paints direct from the manufacturer. Shipments within three days from our plant, or from nearby warehouse stocks. Send for free, informative "Engineers' Painting Guide." Just write on your firm's letterhead, giving your title.

**Be sure to ask about Florwear®, Inertol's chemical- and wear-resistant paint specifically formulated for concrete floors.**

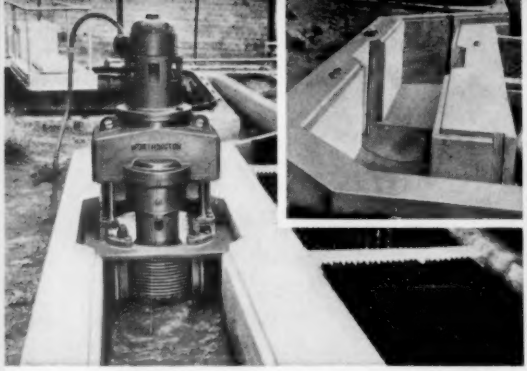
**Rustarmor®—for large non-submerged steel areas.**

Glossy, tough, long-oil alkyd resin enamel in color. Flexible, follows expansion and contraction without checking. Inhibits rust, prevents rusting.

*A Complete Line of Quality Coatings for Sewage Plants and Water Works*

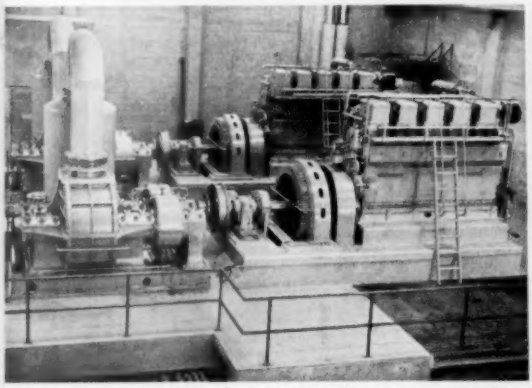
Inertol — INERTOL CO., INC.

482 Frelinghuysen Avenue, Newark 12, New Jersey
27H South Park, San Francisco 7, California

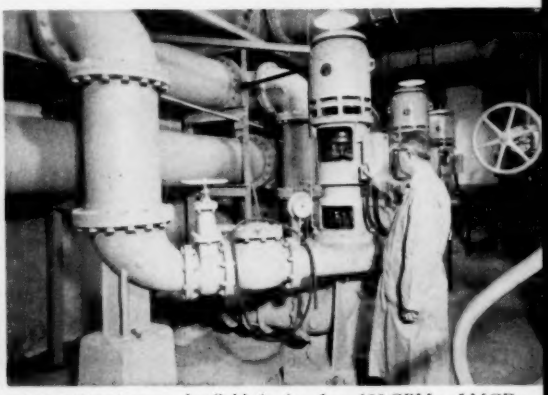


**COMMINUTORS.** Since raw sewage flows straight through in the Worthington design, the comminutor can be installed in a simple rectangular channel (inset) without expensive masonry work. This one is located at Klamath Falls, Ore.

**MIXFLO PUMPS.** Available in sizes from 2 MGD to over 300 MGD, Mixflo pumps have non-clogging sewage-type impellers for passing large solids. This one handles raw sewage in the new Salem, Ore., Treatment Plant.



**DUAL-FUEL ENGINES.** Operating on oil or gas or any combination of both, these Worthington dual-fuel engines drive blowers for the Little Ferry, N. J., Treatment Plant of Bergen County Sewer Authority.



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# SEWAGE AND INDUSTRIAL WASTES

*Journal of the Federation of Sewage and Industrial Wastes Associations*

Volume 29 | June, 1957 | Number 6

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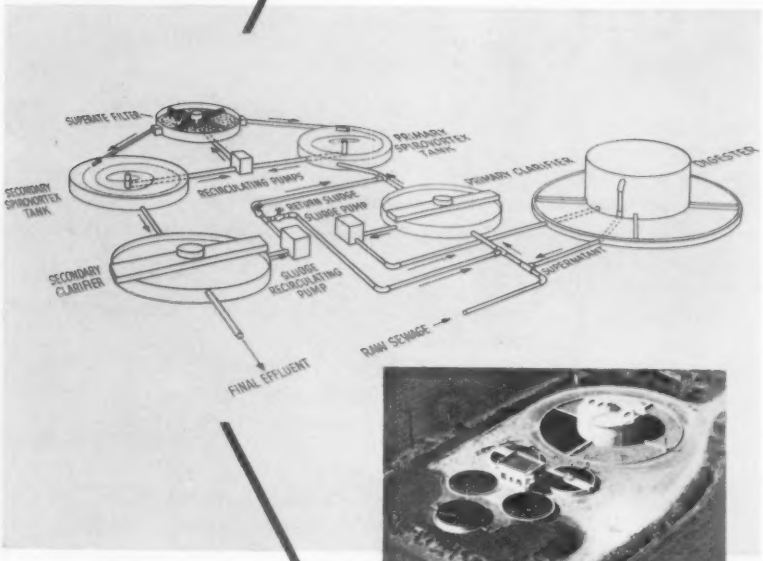

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# 1956 Literature Review

## A REVIEW OF THE LITERATURE OF 1956 ON SEWAGE, WASTE TREATMENT, AND WATER POLLUTION

By H. Heukelekian, *Chairman*, R. Manganelli, *Vice-Chairman*, H. Amberg, R. A. Canham, W. E. Dobbins, G. P. Edwards, M. B. Ettinger, D. G. Foulke, T. deS. Furman, I. Gellman, A. E. Griffin, H. G. Harding, R. D. Hoak, W. M. Ingram, P. W. Kabler, M. Katz, F. W. Kittrell, L. J. McCabe, P. H. McGauhey, W. A. Moore, P. K. Mueller, R. Porges, E. R. Roth, L. R. Setter, A. J. Steffen, C. M. Tarzwell, G. H. Teletzke, W. W. Towne, H. A. Trebler, E. C. Tsivoglou, and R. L. Woodward.

*Committee on Research, Federation of Sewage and Industrial Wastes Associations*

This second of three sections of the review deals with industrial wastes and radioactivity. The first section, dealing with analytical methods and sewage was published in the May, 1957 issue of This Journal. The third section, dealing with water pollution will be published in the July, 1957 issue of This Journal.

### INDUSTRIAL WASTES

#### Food Processing Wastes

In a review of past and present canning waste treatment practices Ingols (62) discusses some of the older methods such as screening, aeration, anaerobic digestion, lagoons and trickling filters.

Further efforts at increased efficiency of product handling and in-plant waste loss control to reduce the solids leaving the plant are emphasized by Neale (97) who stated that such practices could effect reductions in pollutional load of 50 to 60 per cent.

Treatment of canning waste by forms of aeration continues to receive attention. A report by Eckenfelder and Grich (43) reviewed the earlier full-scale work (which has since been abandoned) using activated sludge treatment of waste from a plant handling tomatoes, apples, and peaches. The report states that B.O.D. removal efficiencies of 80 to 90 per cent are obtained with operating costs favorably compared to conventional treatment methods. Baudoin (20) told of treatment tests of sweet potato canning waste in combination with domestic waste in an activated sludge plant. In

this instance it was reported that the success of treatment depends on proper conditioning of the sludge.

While lagooning does not appear as popular as it did a decade ago, a report by Jones (65) discussed earlier work in relation to the evaluation of pigmented, non-sulfur organisms present at times when minimum offensive odors were noted in lagooned canning waste from peas and corn. Several cultures isolated from the lagoons were studied. Only slight success was reported from attempts to establish a heavy population in actual lagoons. In this work, evaluation of the effectiveness of such organisms in reducing odor is not made. There is no indication of further extensive work along these lines due, primarily, to the widespread trend to spray irrigation.

Citrus waste studies by Lackey *et al.* (71) and McNary *et al.* (89) utilizing the activated sludge method are again reported. The McNary *et al.* (89) pilot plant revealed that the use of nitrogen and phosphorus as nutrients is necessary to start the active flora. Efficient operation depends on limits of B.O.D. and solids within certain ranges. When not overloaded the system showed average B.O.D. reductions greater than 99 per cent with the maintenance of some sludge control. Lackey *et al.* (71) also found that certain limitations were present. These included a maximum B.O.D. limit of 3,500 p.p.m., pretreatment by chemical precipitation, regulated waste flow to prevent slug discharges of concentrated waste, aeration for a minimum of 6 hr., nutrient supplements of nitrogen and phosphorus, and final treatment by trickling filter or lagoon.

Some of the experiences of one of the large canning firms handling peas and corn are related by Monson (94). Chemical cost of treatment for odor masking of lagooned waste is quoted at \$0.06 to \$0.07 per case. Limitations of the ridge and furrow irrigation method, as well as details of successful operation of spray irrigation, are recounted.

Spray irrigation continues to be the most popular method of waste treatment. However, there are many problems in this connection as pointed out by Canham (30). The background of the method is reviewed and the necessary components are outlined. Particular emphasis is directed to the need for an adequate cover crop and proper management in operation. Brown and associates (26)(27) and Lane (73) also reviewed irrigation practices. Brown *et al.* (27) discussed the early work done in Ohio on comminuted tomato, beet, carrot, and potato solids for inclusion with spray irrigated wastes.

Reports from Nolte (105) and Jensen (64) concerning the beet sugar industry indicated that considerable emphasis is being placed on the importance of separate consideration for the various waste waters. In-plant improvements such as recirculation of water within the processes and the subsequent relationship with fresh water were presented. Re-use of certain waters was included in the discussions.

The broad field method of handling beet sugar waste was reported by Jensen (64) and Hopkins *et al.* (60). Improvements at the site of earlier work in beet waste management and the field layout are presented by Hopkins *et al.* (60). The physical changes produced a 55 per cent B.O.D. reduction, virtually complete removal of suspended solids, 63 per cent removal in pounds of B.O.D. applied to the field, an alkalinity reduction of 69 per cent, complete elimination of nitrite nitrogen, and a 94.3 per cent removal of ammonia nitrogen. Considerable water loss was encountered on the field both by evaporation and infiltration.

The corn products industry reported on investigations of several methods of treatment. Hatfield *et al.* (56) found that a corn products refining waste can be treated by a two-stage recirculating trickling filter unit at loadings of 4 lb.

of B.O.D. per day per cubic yard. Treatment of influent waste of from 500 to 2,000 p.p.m. B.O.D., using a feed rate of 0.25 to 0.5 g.p.m. and a recycle ratio of 10 to 1 produced effluents of 100 p.p.m. B.O.D. or less. Careful operational attention was necessary to produce efficient results, and in this study the loading limit was not reached. Foley *et al.* (46) reported on an aerobic treatment process for the recovery of usable soluble organic material from dilute solutions obtained from the corn wet milling process. The full-scale plant operated at 90 per cent efficiency at a cost of $70,000 per year and represented a capital investment of $172,000. It was reported that the reduction in waste treatment charges plus the solids recovery offset the operating costs.

Anaerobic digestion followed by hydrogen sulfide removal before biological filtration was found effective in reducing chemical oxygen demand of a corn starch factory effluent (131).

Anaerobic digestion reduced C.O.D. (oxygen absorbed from K $MnO_4$ in 4 hr.) from about 2,000 p.p.m. to 200 p.p.m. Dilution of digester effluent with settled sewage in ratio of 5 to 1 and then biological filtration further reduced the C.O.D. from about 65 p.p.m. to about 30 p.p.m. and gave a highly nitrified effluent.

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## Dairy Wastes

All authors continued to recommend the utmost in waste saving. According to a German report (8) two plants in Sweden have installed stainless steel collecting pans with grids in the floor to collect separately all wastes containing milk residues. The collected rinse milk is concentrated by evaporation and used for feed. Nolte (104) discussed the installation of grid-covered funnels in the floor at places where drips and overflows are apt to occur. These floor funnels have an arrangement for discharge either to drip collection cans or to the sewer. Schulz (123) reported on the impurities in drip and rinse milk and made suggestions for minimizing contamination of these drainings.

The interest in spray irrigation of dairy waste continued. McKee (86) reported on spray irrigation installations at six Kraft cheese plants. Lane (73) reported on the successful disposal of waste by spray irrigation at three dairy plants in different parts of the country. Otten (108) and Prasse (116) reported on experiences with spray irrigation of dairy wastes in Germany.

The Subcommittee on Dairy Waste Disposal of the Dairy Industry Committee (38) published a report listing the research that has been done and is planned in the various institutions encouraged and sponsored by the committee. Some of this work has been reported in earlier years. This report contains some experimental data (not previously published) from work done in 1947 at Michigan State University. It is interesting to note that batch aeration of dairy waste followed by settling for 1 hr. gave 88 to 95 per cent reduction in B.O.D. This was a fill-and-draw method with 10 per cent of the sludge retained for seeding.

Porges and associates have continued work on the fundamentals of the biochemical oxidation of dairy wastes. In one paper (115) they discussed purification, oxidation, synthesis and storage. In another paper (63) they reported on the isolation and study of sludge microorganisms. Lembke (76) in Germany also isolated a number of microorganisms from activated sludge and from anaerobic sludges and investi-

gated the biological activity of the various organisms.

Nolte (103) reported on pilot-plant tests in Germany with the Kessner-type activated sludge plant. For many years this type of treatment has been used successfully for dairy waste in Belgium and elsewhere. In another paper (104) he reported on pilot-plant work with three different types of aeration plants; (a) an Infilco Aero-Accelerator unit, (b) an Aquapura unit, and (c) a Gansloser unit. Process "a" was sufficiently successful so that a full-scale plant is being built. Process "b" used Kessner aerators and also included the addition of phosphates. It has just been started in operation. Process "c" used a combination aerator and mechanical agitator that is claimed to be extremely efficient. A later paper by Kannemeyer (66) indicated that units "a" and "b" gave excellent results, while unit "c" had just been started. This later report gives more complete data, drawings, and costs for all three units. It will be of interest to learn if these relatively complicated units have any advantages in performance or ease of operation over the simple aeration units used in the United States and discussed in a recent paper by Trebler and Harding (139). These authors discussed the merits and shortcomings of various methods of aeration, both as regards trouble-free operation and power cost per pound of B.O.D. removed.

Zack (152) reported on two fairly large dairy waste treatment plants using high-rate, recirculating trickling filters with two stages concentrically arranged. The plants had two-stage clarification using split clarifiers. The author claimed that this construction is actually less costly than for activated sludge-type plants with similar performance.

Svoboda (135) studied dairy waste disposal by a two-stage anaerobic fermentation (as described by Pien in previous years). He concludes that this process is suitable for Czech conditions.

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## Packinghouse Wastes

Russell and Axon (121) reported on the design of an activated sludge plant preceded by a roughing filter to treat 1.0 m.g.d. of municipal and 0.23 m.g.d. of packinghouse wastes, the latter was pretreated at the source to 500 p.p.m. of B.O.D. Solids removal is by chemical treatment and coil-spring filter in lieu of conventional digestion.

In anaerobic digestion research conducted by the Water Pollution Research Board (Great Britain) (144), optimum temperature for two-day digestion was found to be 92° F., with 92 per cent B.O.D. removal. Average results of three months of operation of laboratory-scale digestion at 95° F., with a raw B.O.D. of 2,300 p.p.m., showed average removal of 89.3 per

cent at a mean retention period of 44 hr. This retention time is considerably greater than the 12 hr. reported previously by Schroepfer (THIS JOURNAL, **28**, 6, 707; June, 1956).

Studies on the treatment of wastes from small slaughter-houses, reported by Kountz (70), indicated that chemical treatment with hypochlorite is most practical, provided the pH is lowered with alum to approximately 4.3. The method was found superior to activated sludge and biological filtration because of its flexibility and simplicity of operation without laboratory controls. Raw B.O.D. values of 1,000 to 3,000 p.p.m. were reduced 95 per cent or better. A further reduction could be obtained with process cooking in the plant, because hypochlorous acid will not completely precipitate protein hydrolysed by cooking. Costs average $0.05 per hog for hypochlorite plus the cost of 10 to 20 lb. of alum per 1,000 gal. of waste. Laboratory studies, showed a 93 per cent B.O.D. removal in septic tanks with 10-day detention. This decreased to 78 per cent for a four-day detention. Intermittent sand filters yielded 95 per cent B.O.D. reduction in summer and 85 per cent in winter. Two filters were used in series, dosed four times daily at 200,000 g.p.a.d. at 2-hr. intervals, using screened and settled wastes.

A review paper (142) brought out German practices, which consisted primarily of coarse solids removal prior to discharge to municipal sewers. Opinion is expressed that slaughterhouses (as against meat processing or packing plants) need not pretreat for grease removal because fresh fats will not clog sewers and will improve gas yield in treatment plant digesters. Compartmented tanks are discussed, with grease recovery in the first section and solids recovery in the second and third. Biological filtration is the only secondary treatment mentioned. An extensive discussion of effluent re-use indicates that water shortages are a problem.

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## Fermentation Wastes

Pearson *et al.* (112) reported the results of high-rate anaerobic digestion studies on winery wastes including lees, conventional stillage, and lees stillage. Loadings of 0.1 to 0.2 lb. of volatile solids per day per cubic foot produced at least 70 per cent reduction of volatile solids. The possibility of using digester gas heat to operate the brandy still is suggested. Production of a high quality effluent would require secondary aerobic treatment. Newton (100) described a trickling filter plant designed to handle equal volumes of sanitary sewage and brewery wastes. Howe and Paradiso (61) reviewed design and performance data of a plant consisting of modified aeration, digestion, and trickling filtration to treat principally antibiotic spent beers. An effluent containing 12 p.p.m. B.O.D. and 20 to 40 p.p.m. suspended solids and averaging 5 m.g.d. is discharged to the receiving stream. In-plant practices such as evaporation, filtration, and drying to recover animal feed values are also described.

## Pharmaceutical and Chemical Wastes

Majewski and co-workers (81)(133) reviewed treatment practices at a large organic chemical works. Two 225-ft. filters are operated in series at recirculation rates of 16 to 1 and 6 to 1. Over-all efficiency exceeds 90 per cent at loadings of 1 to 2 lb. of B.O.D. per cubic yard per day. Provision is made for temporary storage of toxic wastes and gradual discharge to the filters. Final effluent is impounded for one to two months, chlorinated, and stored again for up to one month before dis-

charge. Effluent B.O.D. average is 10 p.p.m. Extensive data on response to shock loads and seasonal efficiency variations are presented, along with details of safety features designed to prevent discharge of toxic materials to the potable receiving water.

Montes *et al.* (95) described wastes resulting from petrochemical processes and summarized waste treatment problems and progress at a large midwestern plant. Effluent is neutralized and discharged to large oxidation lagoons with 18-day retention. These have proven effective in reducing 90 to 95 per cent of the influent B.O.D. at loadings of 75 lb. per acre per day. Effluent generally contains more dissolved oxygen than the receiving stream.

Dryden *et al.* (42) discussed laboratory and pilot-plant studies of biological oxidation of fine chemical wastes. Factors studied included contact time and B.O.D. sludge loading. Treatment of excess activated sludge by aerobic digestion was studied and found promising. Probability charts and the development data were used to calculate the full-scale design criteria. Watson *et al.* (145) discussed waste disposal considerations involved in location of a new hypothetical chemical plant. The contributions covered such areas as the management's reasons for location, the regulatory agency position regarding treatment requirements, development of disposal process design, role played by consultants, selection of a contractor, and operational procedures.

Eckenfelder and O'Connor (44) described a small treatment plant for paint and pigment wastes. Treatment consists of equalization, chemical coagulation with alum and sulfuric acid followed by sedimentation, pressure sand filtration, and chlorination. Sludges are discharged to a lagoon and the plant effluent enters a stream used for recreational purposes.

Nicolai *et al.* (101) discussed treatment facilities for a rubber research laboratory. Polymer wastes are concentrated to 10 per cent solids by submerged combustion and the concentrate is dried on beds. Sanitary sewage and chemical laboratory wastes receive activated sludge treatment. Reinhart and Glas (118) studied chemical precipitation of uranium refining wastes using magnesium line. Neutralization of uranyl nitrate wastes to pH 8 produced a magnesium diuranate precipitate which thickened to 30 to 40 per cent solids and removed 90 per cent of the uranium content at influent concentrations of 0.1 to 3 per cent uranium.

The DuPont Co. (6) developed a continuous automatic organic carbon process waste stream analyzer which has been installed in a number of instances. It employes a continuous oxygen consumed and thermal conductivity procedure to detect process spills and other excessive chemical losses. Cost of these units is high but may be justified in some cases.

## Coal Wastes

A closed system, described by Shlomov, Voronov, and Perov (128), proved to be highly economical for water recovery at a coal washery. Recycled water is pumped from a sump to a surge tank, and thence to a battery of middlings centrifugals to serve as wash water. Next the flow is to the flotation feed tanks to dilute the pulp, and finally the water returns from the thickeners to the sump. Economy results from elimination of ponds for waste water treatment and waste of fuel values in slimes, amounting to 4.5 per cent; increase in yield of clean coal by 2 per cent; and reduction of water consumed by 24 to 120 gal. per ton of coal processed. The closed system can be installed in any efficient washery by a slight alteration in the slime settlers. A flowsheet and sketches of equipment illustrate the process.

Berthold (21) discussed the theory of hydrocyclones and reported experi-

mental data on separation of brown-coal dust and ash from water. The paper includes performance curves. Liegeois (78) gave the average daily output from six Belgian basins, and discussed new developments in water classification, recovery of slimes, and elimination of clays. Lord (79) patented a method for recovering powdered coal and powdered high-ash solids from waste water by froth flotation. Van Ness (140) reported that the plant for recovering coal which has settled on the bed of the Susquehanna river has been producing upwards of 500,000 tons annually of useable steam sizes of anthracite coal since the operation began in 1953. The river coal runs 10,000 B.t.u., 16 per cent ash, 18 per cent moisture. Full details of the operation are given.

Coal-mine drainage causes serious pollution in various parts of the country, and the problem of controlling it has stimulated considerable research. Braley (24) published the results of a series of studies from which he concluded that (a) gaseous inhibitors cannot be applied successfully to the interiors of abandoned mines; (b) phosphates, chromates, or caustic soda have little effect on the rate of oxidation of iron pyrite, either wet or dry; (c) the rate of oxidation of sulfuritic material is greatly increased by aeration, either wet or dry; (d) pH is a poor criterion of reaction rate in buffered solutions; and (e) there is no known inhibitor, capable of slowing or stopping the reaction between oxygen and sulfuritic material, that can be used practically in abandoned mines. (*Abstractor's Note*—The U. S. Patent Office has refused to issue a patent on the method developed at Johns Hopkins for inhibition of acid formation in coal mines.) Temple (137) summarized available information on acid formation.

The effects of coal mine drainage were the subject of two investigations. Lewis and Peters (77) reported the results of a joint study of the concentrations of slag drainage that will cause fish mortality. The acidic drainage has the following characteristics: total acidity as calcium carbonate, 1,360 p.p.m.; pH 2.3; total iron, 2,700 p.p.m.; and specific conductance, 8,000 reciprocal megohms at 25° C. The lethal concentration of the mine water was about 1 part in 50 for green sunfish, largemouth bass, and carp obtained from a farm pond. Mineral acidity was the most important factor in fish mortality; pH 3.5 caused death in a short time, and values of 4 to 4.5 caused pronounced gill irritation. Neither oxygen depletion, iron flocculation, or salt content were found to kill fish.

Parsons (111) studied a stream subject to pollution by coal mine drainage. The upstream section was continuously polluted, and the lower section periodically received excessive flows of mine water. The chemistry of the upstream section was little affected by heavy flows of mine water, but in the lower section the bicarbonate buffer system was destroyed, there was a slight lowering in dissolved oxygen, and a slight increase in the ions associated with mine water. But, the toxic factor appeared to be the acid content as measured by pH and titratable acid. Neither the plankton nor benthos populations of the polluted section appeared to be affected by excessive acid flows; the population was not unlike that in the septic zone of organic pollution. But excess acid drastically reduced the plankton population of the lower section; the population remaining after such a flow was composed entirely of rotifiers. Fishes were restricted to the unpolluted section; here an acid flow at pH 4 and titratable acidity of 100 p.p.m. was fatal.

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## Coke Oven Wastes

Chlorine reacts with phenol in acid solution to yield 2,4,6,-trichlorophenol. This compound can activate the fungicidal property of pentachlorophenol, and can be converted to a hydroxyacetic derivative which acts as a plant hormone. Guinot and Tinchant (52) proposed using this reaction as a basis for treating coke oven still waste. They state that trichlorophenol is sparingly soluble in water and that any remaining in solution can be extracted with benzene or petroleum ether, which have partition coefficients of 80 to 200 for this compound. They point out that chlorination oxidizes other labile impurities at the same time, and that a high degree of purification results after neutralization of the final liquor with lime. Landa (72) proposed selective extraction to recover ketones, alcohols, esters, and ethers from phenolic waste water. The higher ketones (methylbutyl ketone) will separate monophenols from diphenols, and the phenols can be oxidized to dibasic aliphatic acids, such as $\beta$-ketoadipic, malonic, oxalic. He states that treatment by ion exchange or microorganisms is also feasible for recovering byproducts from phenolic wastes.

Podbielniak and Kaiser (114) described the Podbielniak solids-handling centrifugal contactor. The device is comparable to gravitational mixer-settler equipment and may be visualized as a tray tower with the trays wrapped around a rotating shaft which develops a high centrifugal force instead of gravity. Use of 2,000 gravity permits countercurrent extraction in a low holdup, high throughput machine. Extraction of more than 99 per cent of the phenol from coke oven waste is claimed, with caustic consumption of about 1 lb. per pound of phenol removed. The machine should permit use of solvents with a high selectivity for phenols; such solvents have found limited application because of high cost, high holdup, small density differentials, and tendency toward emulsion.

A method for recovering values from coke plant ammonia liquor was proposed by Neef (98). The liquor is treated with coke dust, and the dust is filtered, briqueted, and heated to a high temperature. It is claimed that the condensate contains valuable compounds and that the final briquets are worth more than the coke dust. Williams and Solt (148) patented a method for purifying ammonia still waste. After removal of thiocyanates and thiosulfates by ion exchange or by oxidation, passage of the liquor through activated carbon results in pickup of coloring matter and tar acids. The adsorption is irreversible, and shortens the life of the carbon. This is overcome by first passing the liquor through an ion exchange resin of large pore size, prepared as follows: a solution is made of 9.75 lb. of m-phenylenediamine in 7.5 gal. of water and 1.35 gal. of muriatic acid; 2 gal. of 40-per cent formaldehyde is then added. The mixture sets to a solid gel which is cooled and granulated through a 10-mesh sieve. It is boiled 30 min. with 23 gal. of 10-per cent formaldehyde, separated, and boiled 15 min. with 2.5-per cent caustic soda. The separation and boiling steps are repeated twice. The resin is washed to remove fines and stored under water.

Arden (17) described a new production unit for purification of coke plant waste in England. The process uses De-Acidite E, a weak-base resin, for removing thiocyanates and thiosulfates. These ions have such a high affinity for strong-base resins that it is almost impossible to elute them. They are removed completely in this process by regeneration with ammonia. The free and fixed ammonia is recovered from the eluate by distillation from lime, and recycled. The resin is converted to the chloride form with hydrochloric acid. The effluent is discharged after treatment with activated carbon to remove phenols.

Page (109) found that a bacterial culture which would destroy phenols almost completely had little or no effect on thiocyanates. However, another culture was effective on the thiocyanates, and a two-stage biological process was developed. The best sources of phenol and thiocyanate consumers, respectively, were any well-manured soil and soil from an old coal storage site. Optimum temperature for oxidation of phenol was 40 to 45° C., for thiocyanates 35 to 40° C. Polyhydric phenols were reduced to 36 p.p.m. from 170 p.p.m., monohydric phenols to 0.4 p.p.m. from 610 p.p.m., and thiocyanates to 0 p.p.m. from 381 p.p.m. Operating data and analytical methods are given, but the bacterial strains are not named.

Delyagin (40) pointed out that extractive recovery of phenols from gasworks effluents is not economical unless the concentration exceeds 2 g. per liter. He described a bio-oxidation process in which the main features are the recycling activated muds and the addition of phosphoric acid. The optimum pH for aeration is 6 to 8 at 20° C. Hydrogen sulfide must not exceed 0.3 to 0.5 p.p.m.

Bethlehem Steel (7) arranged with Bethlehem, Pa., to discharge its dephenolized coke plant waste to the municipal sewage treatment plant.

An evaporation process for making first-grade ammonium sulfate directly from coke oven gas has been reported by Kennaway, Wood, and Box (68). The process differs from conventional methods in that the gas stream is scrubbed with dilute sulfuric acid and the solution is fed to a vacuum evaporator. The authors concluded that there is little difference in capital, operating, and maintenance costs between the evaporation process and either the direct or the semi-direct processes. They claim that production of sulfate crystals outside the main gas stream is an outstanding advantage of the new process. Tod and Simpson (138) compared ammonia liquor with nitro-chalk and ammonium sulfate for fertilizing grassland, potatoes, and rutabagas. They concluded that ammonia liquor represented a useful source of nitrogenous fertilizer, provided it could be made available cheaply and precautions were taken to minimize scoreh.

Gwilliam *et al.* (54) carried out laboratory experiments on the biological filtration of gas liquor and some of its constituents. It was found that phenols and thiosulfate were readily oxidized biologically. Thiocyanate gave more difficulty, and higher tar acids were particularly difficult.

A flotation process for recovery of naphthalene was described by Gisler (51). The process is said to operate with low maintenance and power costs. Recovery of naphthalene nearly quadrupled at one plant after installation of flotation.

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### Petroleum Processing Wastes

Davis (39) reviewed the microbial decomposition of hydrocarbons and presents data from experiments in flasks for crude oil, showing percentage decomposition by class of hydrocarbon. Amounts of water-soluble products (acids and alcohols) are shown to be insignificant. Discussion is given on aliphatic and cyclic hydrocarbons. Biological disposal by bacteria, actinomycetes, filamentous fungi, and yeasts is believed feasible if optimum conditions of aeration, agitation, and nutrient supply are maintained. Applied aspects of microbial decomposition are pointed out to be preceding the development of fundamental knowledge. Starkey (132) discussed aerobic and anaerobic transformation of sulfur compounds. Species of microorganism and suggested reaction paths are presented. Corrosion aspects are also included.

A series of laboratory-scale experiments on the aerobic biochemical oxidation of a medium grade commercial motor oil are reported by Ludzack and Kinkead (80). Effectiveness of bacterial seed from sewage, river, and refinery sources are checked by oxygen depletion of octadecane suspensions. Oil reduction is 30 to 50 per cent per week from an initial level of 100 mg. per liter at 20° C. A persistent odor is noted, whereas the bulk of the oil is oxidized. Infrared analyses and chromatographic separation are not successful in distinguishing the odor component. Air recirculation (agitation), frequent addition of seed, and starting with a uniform oil emulsion are important factors in achieving oxidation. Variation in temperature shows 50 to 80 per cent oxidation at 25° C. down to no apparent activity at 4° C. The most prominent intermediate products are isolated and identified as acids and esters. Biological stabilization of oil emulsions is mentioned.

Microbial oxidation studies of soluble oil emulsions and emulsifiers by *Pseudomonas oleovorans* and *Pseudomonas formicans* are presented by Sabina and Pivnick (122). Respiration studies of oxygen uptake are conducted with washed bacterial cell suspensions in the presence of 2 per cent soluble oil emulsions or 0.5 per cent emulsifying agent at 30° C. Culture methods and growth medium are given. The soluble oils are complex mixtures of mineral oils, fatty oils, emulsifiers (petroleum sulfonate soaps, fatty acids, resin or naphthenic acids), coupling agents (alcohols or high boiling ethers), extreme pressure additives (sulfurized fatty oils), rust inhibitors, and contaminants, and they show considerable variation in susceptibility to oxidation. Soluble oils containing oleates or fatty materials are readily oxidized. *P. oleovorans* attacks an oil containing petroleum sulfonate whereas *P. formicans* does not. However, *P. oleovorans* does not oxidize petroleum sulfonate in emulsifier studies under the conditions studied. Soluble oils containing naphthenates or resinates show slight oxidation. The possibility is pointed out of long-term bacterial adaptation or inoculation to give oxidation of petroleum sulfonate soluble oils in contrast to short-term experimental results.

Baker and Weston (19) presented pilot-plant data for biological filter and activated sludge decomposition of refinery wastes. Effects of lead, temperature, detergent, and B.O.D. loading are given. Lead levels above normal values do not destroy biological activity but do result in some decrease in efficiency of B.O.D. and C.O.D. removal. No detrimental effects on filter operation are noted for detergent levels up to 25 p.p.m. Percentage removals for B.O.D., C.O.D., and oil are summarized for activated sludge treatment; the mean values being 55.2, 39.3, and 84.4 per cent, respectively. Preparation (conditioning) of the influent is required.

Ross and Sheppard (120) set forth considerable data on activated sludge

biological oxidation of phenolic waste waters. Effective organisms in phenol destruction also utilize cresols and organic acids, aldehydes, alcohols, and ketones. Efficiency of removal for phenolics is 99.9 per cent at 300 p.p.m., and 99 per cent at 450 p.p.m. Survival of bacterial activity for up to 24 hr. is noted for phenol levels as high as 1,600 p.p.m. Prolonged levels greater than 500 p.p.m. result in marked decrease in efficiency. Optimum temperature is 100° F. and efficiencies are essentially unchanged over a pH range of 4.5 to 8.8. Copper up to 100 p.p.m. and hydrogen sulfide up to 50 p.p.m. have little effect. Feed surge capacity is advocated to avoid shock changes in pH ($> 8.8$), sulfide, free oil, and excessive C.O.D. A capital investment of $230,000 (1954) is reported for an 800 lb. per day phenol plant.

Chasanov, Kunin and McGarvey (33) present data on the sorption of phenols by anion exchange resins for synthetic mixtures and industrial wastes. Effects of pH, flow rate (vol./vol.), resin type, regenerants, phenolic type, and concentration of ionized solids present are given. Quaternary ammonium anion exchange resins (hydroxyl form) are stated to be practical for industrial-scale removal of phenols from wastes. Small space requirements for a plant installation are pointed out.

Ozone oxidation of phenolics in petroleum waste waters is presented by Niegowski (102). Ozone concentrations at about the 900 p.p.m. level destroy 99 per cent of the phenolics in sour condensate and caustic wash waters. An on-the-site ozone generator yields a dilute ozone mixture which is dispersed in the phenolic waste. Laboratory studies utilize a sieve-plate tower. Optimum pH is 12, but oxidation proceeds at all pH levels. Ozone demand (at 99 per cent removal) is in the ratio of 1:1 to 10:1 of phenol content depending on other wastes present. Sulfides show a high ozone demand but this is decreased by preaeration. Reduced B.O.D. and C.O.D. accompanies phenol reduction. Partial treatment plus dilution of effluent is suggested. A plant to treat 800,000 g.p.d. of waste water and requiring 1,260 lb. per day of ozone is estimated to cost $380,000.

Wedgwood and Cooper (146) presented analytical procedures for polynuclear aromatic hydrocarbons in various sewage and industrial wastes. Basic steps are extraction by chloroform, chromatographic fractionation, and spectrophotometric examination of the fractions. Compounds identified are listed.

A compilation by McKee (87) on oily substances and effects on beneficial uses of water also compares analytical methods and state standards on a country-wide basis.

Brown (28) disclosed a patented gas-flotation process for the recovery and removal of oil from oil-contaminated water. Recovered oil is washed by a countercurrent water stream and the water phase is subjected to gas flotation in various equipment arrangements to give multi-stage treatment.

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## Pickling and Acid Wastes

A pickling and recovery process was patented by Miller (92). Steel is pickled with sodium bisulfate, which results in formation of ferrous sodium sulfate. The spent bath is neutralized to pH 7 to 8.5 with ammonia and blown with air to oxidize the gelatinous ferrous hydrate to an easily filterable black or brown oxide. The filtrate is substantially a solution of sodium ammonium sulfate. It is evaporated to crystals, which are thermally decomposed to bisulfate and ammonia for recycling. The iron oxide is a by-product. Heinrich (57) believed that there were no insurmountable technical problems in a closed-circuit pickling system whereby ferrous sulfate is precipitated as the monohydrate and converted to fresh acid for re-use. Manke (82) patented a process for regenerating spent pickle liquor wherein basic sulfate is crystallized by treating the liquor in an autoclave at more than 250 p.s.i. at 350° F. with air, oxygen-enriched air, or oxygen. It is claimed that about 90 per cent of the iron precipitates as a readily filterable basic sulfate.

A study of sludge volume control in neutralization of acid wastes was made by Faust, Orford, and Parsons (45). They found that sludges, formed when sulfuric acid is neutralized with lime, can be concentrated by adding gypsum

or returning previously-formed sludge to the acid before neutralization. The optimum return of sludge appeared to be 1 to 3 times the weight of calcium sulfate formed by the neutralization. Wunderley (151) patented a method for neutralizing spent pickle liquor with blast furnace slag, and a vessel (150) for carrying out the process.

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### Plating and Cyanide Wastes

Emphasis in the metal-finishing industry continues to be placed on the reduction of waste volumes. Odland and Hessler (107) point out the importance of reduced rinse flow when planning concentration of waste water. They show how zinc cyanide and chromic acid wastes may be concentrated by evaporation to save not only the cost of chemical destruction but to produce a profit for the operation. Neff (99) compared the batch and flow-through chlorine treatment of cyanide wastes; again low rinse water volume is important. Mohler (93) described the use of a conductivity control to make economical use of water for rinsing by limiting the flow of water so that the rinse water contamination does not exceed a certain value. Draining time of less than 15 sec. will result in excessive water use. The value of 0.1 oz. per gallon of contaminant is considered a good setting for a controlled rinse tank.

Keating and Duff (67) discussed the economics of treatment methods emphasizing that recovery equipment involves greater capital outlay than destruction. In an anodizing plant the cost was given at $41,000 versus $47,000 for ion exchange recovery. However, the operating cost for the former plant amounted to $4.35 per day whereas for the recovery process a credit of $10.30 per day was possible. For a mixed waste effluent, it was shown that a water recovery installation, besides being more costly, would be more expensive to operate.

Abrams (1) discussed the selection of an ion exchanger for use with plating wastes. A classification of commercial ion exchangers is given. Cross-linked styrene divinyl benzene resin is useful for chromic acid solutions while the polystyrene sulfonic cation exchanger has widest use in the plating industry. A fairly porous resin matrix is usually required to prevent fouling.

Small and Graulich (129) described lagooning as of limited applicability for plating wastes. Ion exchange was feasible only if recovery of water and chemicals could justify the procedure. However, precipitation, thickening and filtration was the most satisfactory means of waste disposal.

The oxidation of cyanide wastes by chlorine and hypochlorites was covered thoroughly from the processing standpoint. (32). It was shown that if the first stage of chlorination is carried out at a pH of 9.0 and the second stage at a pH of 7.5, then complete oxidation to nitrogen and carbon dioxide could be effected in 15 to 20 min.

The effect of metal plating wastes on sewage treatment (136) was studied under conditions involving the simultaneous feeding of plating solutions containing chromium, copper, nickel, zinc, and cyanide to mixtures of activated sludge and sewage at several Ohio installations. It was concluded that these mixtures had a detrimental effect on the ability of activated sludge to remove B.O.D. from sewage. At the Marion, Ohio, sewage treatment plant,

part of the copper, chromium, and cyanide was removed in the primary settling tanks and part in the trickling filters. There was more removal of cyanide than copper or chromium in the plant. At the Selby, Ohio, sewage treatment plant some concentration of metals occurred in the activated sludge. At St. Mary's, Ohio, and Marion, metals from plating wastes accumulated in the trickling filter slime but there was no exact proof that performance was affected.

Gurnham (53) reviewed the investigations on the effect of as little as 2 p.p.m. of cyanide on the inhibition of nitrification. However, recovery was rapid, and a slow and steady increase in cyanide concentration resulted in a tolerance of as much as 200 p.p.m. of cyanide. Simple cyanides and less tightly bound complexes have much more effect than the stable iron and nickel cyanide complexes. Trickling filters acclimatized to 100 p.p.m. of cyanide were found to destroy 99 per cent of the cyanide. Even in the absence of sewage or other organic matter the cyanide was destroyed.

A preliminary report (127) on the behavior of the experimental trickling filter at the Ohio Engineering Experiment Station stated that the standard filter can take up to 4 p.p.m. of chromium as chromium acid. At 4.5 p.p.m. the effect is definitely perceptible and at 5.5 p.p.m. some loss of biological growth on the stone was visible.

In a review of British problems (113), the danger of acidity and high concentrations of sulfates (over 1,000 p.p.m.) was pointed out. There was also the danger to personnel due to the release of free HCN and the presence of chlorinated hydrocarbons in the sewers. Copper, nickel, or zinc have a detectable effect on purification by the activated sludge process if present at a concentration of 1 p.p.m. Rather high concentrations are tolerated by trickling filters. At a concentration of 1 p.p.m., cyanide affects the action of trickling filters and activated sludge. It is claimed that chromate affects the activated sludge and the trickling filter processes at concentrations of 2 and 1 p.p.m., respectively.

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## Pulp and Paper Wastes

The progress of the pulp, paper, and paperboard industries in effluent treatment and control was discussed by Gehm and Brown (50). Based on a recent survey of the industry, it was conservatively estimated that $70 million were expended for waste treatment plant construction in the last 10 years. Gehm (49) discussed briefly some of the American practices in disposing of the effluents from sulfite and kraft pulping operations. The stream improvement programs of the Wisconsin pulp and paper mills were discussed by Mead (90) and Wiley (147).

### *Sulfite Process Effluents*

The sulfite industry, despite tremendous progress, still presents a challenging problem to researchers in by-product recovery and pollution abatement. A patent has been granted to Zimmerman (153) for the treatment of spent sulfite liquor by wet combustion. The oxidation is accomplished by the introduction of heated compressed air under pressure of 1,500 p.s.i. into pressure vessels containing the waste material heated to 480° and 625° F., at which temperature oxidation takes place. Heat recoveries of 95 per cent are claimed, producing power in excess of that required for processing. A pilot plant is described (13) as capable of oxidizing 33 g.p.m. of waste liquor with resultant chemical oxygen demand reductions of 90 per cent and boiler efficiencies of 70 to 80 per cent when generating steam at 150 p.s.i.

A similar system was developed by Cederquist (31). At a temperature of 225° C., the speed of reaction was fairly high and the reaction approached true combustion. Some of the sugars were apparently converted to acids since acetic acid was found in concentrations as high as 10,000 p.p.m. Blikstad (23) discussed the differences between the Cederquist and Zimmerman processes. The Zimmerman process produced 6.2 tons of steam per ton of pulp and the cost of the plant was estimated to be about 40 per cent of the cost of conventional evaporation and burning equipment. Wet combustion was not only advantageous from the point of view of heat recovery, but opened the way to new methods for the recovery of chemicals used in the pulping process. Wet combustion was further discussed by Hansen (55) and Brunes *et al.* (29).

Considerable information has been reported on the evaporation and burning of spent sulfite liquor. The use of the soluble bases, ammonia and magnesium oxide, with subsequent evaporation and burning of the collected spent liquor, has been adequately reviewed in previous publications. Collins (37) described a recovery system for acid, neutral, or alkaline sodium-base sul-

fite liquor. The process involved neutralization and oxidation of the spent liquors, and use of a furnace where all hydrogen sulfide was converted to sulfur dioxide. The furnace served as a sulfur burner. Conventional equipment was used for the addition of make-up chemicals, stack gas cleaning, dust collection, sulfur gas recovery, and cooking liquor preparation. Nugent and Boyer (106) described the conversion of a sulfite mill to sodium-base pulping and the treatment of 40 g.p.m. of the sodium-base liquor in a semi-commercial pilot plant. The pilot plant proportioned the spent liquor with a solution of sodium sulfide and sodium carbonate, clarified the solution of calcium carbonate, and converted the liquor to a kraft-type liquor which was evaporated to 65 per cent. Clarke and Baldwin (35) reported on the combustion of spent sulfite liquor (concentrated to 57 per cent dry solids in channel-switching evaporators of the Rosenblad type) without auxiliary fuel in two Loddby non-cooled preburners installed vertically on the main boiler furnaces.

Kleinschmidt and Bowen (69) discussed the possibilities of improving the over-all heat balance of pulp and paper mills by the use of thermal compression evaporation, either alone or in conjunction with multiple-effect evaporation of conventional form. The characteristics of the mill which tend to favor the application of thermal compression to the concentration of waste liquors, such as relative cost of power and fuel, amount of low-pressure steam used, by-product power available, boiler steam pressure, and temperature, were discussed. A patent was granted to Seymour (126) for a method of evaporating and burning spent sulfite liquor. Heat transfer pebbles of a refractory substance were heated and passed into an evaporator where spent sulfite liquor was introduced. The liquor was evaporated to produce steam which was bled off. The residue deposited on the pebbles was burned when the pebbles were returned to the heater.

Rabinovitch and Gauvin (117) studied the pyrolysis of spray-dried powder obtained from calcium-base sulfite liquor in a batch fluidized reactor. The gaseous products of the reaction were $SO_2$, $H_2S$, $CO_2$, $H_2$, CO, paraffins, and illuminants. A partially-coked solid, amounting to about 50 per cent of the initial charge was produced and maximum sulfur recovery of 70 to 73 per cent was obtained at a temperature of 300° C.

The reduction of B.O.D. by oxidation of spent sulfite liquor with oxygen over a cupric oxide contact catalyst was investigated by Schwabe *et al.* (124). Increase in pH and temperature accelerated oxidation and the oxidation velocity decreased markedly after the first hour. Use of the cupric oxide-iron oxide-cobalt oxide catalyst markedly increased the reaction velocity. A method for the removal of calcium from spent sulfite liquor by means of ion exchange was described by Robinson (119). It was found that a sulfonated polystyrene resin would remove virtually all of the calcium from a raw liquor which originally contained 7.8 g. per liter as calcium oxide.

By-product recovery from spent sulfite liquor received special effort by researchers in the industry. Amberg (4) discussed the production of protein concentrates by the aerobic fermentation of spent sulfite liquor. Pollution reductions ranging from 60 to 90 per cent may be accomplished by fermentation. Utilizing a mixed bacterial culture, 80 per cent B.O.D. reductions may be expected, and B.O.D. reductions as high as 70 per cent have been reported for the torula yeast fermentation process. Analyses of bacterial and yeast protein concentrates indicated that these materials were excellent sources of all of the essential amino acids and were readily used

as a protein supplement in livestock rations.

An aerobic fermentation process was developed by Amberg (3) which employed a mixed bacterial culture capable of reducing 80 to 90 per cent of the B.O.D. of spent sulfite liquor. Approximately 20,000 p.p.m. of bacterial cells were carried in the fermentation unit, which was operated on a continuous flow basis. The fermentation was conducted at B.O.D. loadings of 2,500 lb. per 1,000 cu. ft. of aeration capacity per day. The resultant high yields of bacterial protein have a protein content of 66 to 70 per cent.

A new approach to the profitable utilization of sulfite waste was presented by Bailey (18). An iron chelate was produced from the dried residue obtained from ammonia base spent sulfite liquor. The iron chelate (Greenz 26) was successfully used as a spray for fruit trees to prevent "iron chlorosis." Wallace and Ashcroft (143) also found an iron chelate made ammonium lignosulfonate effective for soil application in supplying iron to plants and in correcting lime induced chlorosis in soybeans.

Calcium lignosulfonate, a product of spent sulfite liquor, was used by Langins and Snow (74) as a dispersing agent in the manufacture of Portland Cement. A mill trial conducted with spent sulfite liquor fed to the slurry at a concentration of 0.66 per cent (based on mineral solids) effected increased milling capacity, reduced fuel consumption, increased production, and improved quality. A new member of a group of surface-active, lignin sulfonate chemicals (ORZAN P) was introduced as a commercial product by a Pacific Northwest pulp mill (9). This product has the property of precipitating readily from solutions and clinging to fibers or other materials present. Another novel use of ammonium lignosulfonate (ORZAN A) was described by Cline and Bloom (36). Silica bricks soaked in a solution of the ammonium lignosulfonate and subsequently dried minimized the dust problem associated with the cutting of the bricks.

The use of spent sulfite liquor to concentrate magnetite ore is presently under investigation (10). The organic materials of the spent sulfite liquor are to be substituted for inorganic compounds now being used in pelletizing the concentrate.

Wisniewski *et al.* (149) presented data on pilot-plant studies to determine the rate of flow and efficiency of soil filtration tests with spent sulfite liquor. This method of treatment was effective in converting the sugars to organic acids and related products. Although sugar reductions of 90 per cent were accomplished in a week, B.O.D. reductions were relatively low. Feed rates of ammonia base liquors of 0.95 lb. per square yard resulted in B.O.D. reductions of 70 per cent in about 24 weeks.

Churchill (34) described the use of spent sulfite liquor in an attempt to eradicate the fish population in a lake. A dosage of 1 part of spent liquor to 4,000 parts of water failed to induce mortality and the experiment was considered a failure.

A problem which has been associated with the discharge of spent sulfite liquor is excessive slime growth in the receiving stream. A joint stream study and research program conducted by the Washington State Pollution Control Commission and Crown Zellerbach Corporation of Camas, Wash., was announced (16). The immediate objectives of this research program are to determine nutritional factors essential for slime growth and to determine the extent to which sulfite effluent, municipal sewage, and other nutrients contribute to the problem. Höhnl (59) conducted extensive laboratory tests on the minimum dilutions of spent sulfite liquor which would support the growth of *Sphaerotilus natans*. A spruce cook of spent sulfite liquor produced growth at a dilution of

1:694,000, spent yeast waste gave growth at a dilution of 1:470,000, and spent liquor from alcohol fermentation produced growth at a dilution of 1:350,000. Amberg and Elder (5) found that intermittent discharge of spent sulfite liquor to river water having a low pollution background produced no significant slime growth, provided the discharge interval was maintained at less than six hr. and preferably below 4 hr.

*Kraft or Sulfate Process Effluents*

Chemical recovery and burning of solids in the sulfate process results in pollution reductions of 85 to 90 per cent. In many locations, particularly during drought flows, additional reductions are required. Water conservation measures and internal pollution reductions by the Southern kraft industry are presented by Brown (25). The general trend by the Southern industry is one of lower fresh water demand per unit of production through the re-use of various waste effluents. The combined condensates, which represent 60 to 70 per cent of the B.O.D. load from a modern unbleached kraft mill, are being re-used in many mills for caustic make-up applications of mud washing, mud filter or dregs washing, brown stock washing, or as condenser water make-up. Continued emphasis on secondary treatment of kraft mill effluents continues.

Moore (96) discussed laboratory and pilot-plant studies together with statistical analyses of the findings, which formed the basis for the design of a treatment plant using minimum-size units and equipment, but capable of handling flow requirements and giving the quality of effluent desired.

The utilization of a natural purification system of effluent disposal developed for a Valdosta, Ga., kraft board mill is summarized after two years of operation (12). The layout of the ponds, operation of the system, and tests made are described. The system is reported to obtain 98 per cent B.O.D. reductions. There has been no change in the river since the mill began operating. Another system was developed by the Eastex Corporation (14) which takes advantage of natural purification facilities. The mill effluent is conveyed by means of a 14-mile canal into a swamp area of 4,500 acres. The high-B.O.D. sewer carries effluents from the recovery, recausticizing, and digester room operations and is discharged into an equilizing basin. The strong wastes are released to the canal at a predetermined measured rate. Two sedimentation basins remove settleable solids from machine waters and bleach plant sewers are discharged directly into the effluent canal. It is estimated that high B.O.D. reductions will be accomplished by this system once an acclimated bacterial slime is developed in the canal.

Bialkowsky and Billington (22) discuss the effluent discharge program of a bleached kraft mill. The non-condensible gases from the digester relief and blow, and from the evaporators, are collected in a 27-ft. diameter spherical gas holder. These gases are fed at a uniform rate of flow to the drop leg of the chlorination washer. In a similar manner, all of the condensates from the digester relief and blow, and the condensates from the evaporators are collected and injected into the chlorination drop-leg sump for oxidation and destruction. No detectable quantities of mercaptan or organic sulfides have ever been found in the effluents after this treatment. The plant wastes are discharged to a holding basin which permits discharge of effluent during the outgoing tide. Surveys of the receiving water course indicate that the effluents are disposed of in such a manner as to eliminate hazards to fish life.

Pilot-plant production of dimethyl sulfide from kraft black liquor has been started by one pulp producer in the Pacific Northwest (15). This opera-

tion with a potential capacity of two million pounds annually, uses a patented Swedish process. Based on present kraft production capacities, the process has a potential dimethyl sulfide output of 75 million pounds per year at a yield of 75 lb. per ton of pulp.

*White Water Effluents*

A three step process for the rapid clarification of white water and an apparatus that is used in the third step is described by Stemen (134). In the first step the white water is rapidly mixed with a coagulating chemical and a ferromagnetic powder. In the second step the mixture is gently agitated to promote the formation of a flocculant precipitate that contains the impurities of the waste and the ferromagnetic powder. In the third step the floc is rapidly removed by a magnetic drum.

Hoesch (58) discussed effluent treatment for fiber recovery by flocculation with ferric sulfate and calcium hydroxide (Pista Process). Chemical-technical questions, biological problems, and economical considerations are pointed out. Friend (48) presented the basic conditions required for the flotation of fibers and described a laboratory device for the evaluation of flotation efficiency.

Schwarz and Hennig (125) subjected white water in an acid condition to froth flotation in the presence of a flotation agent consisting of sulfonated fatty materials and protein solutions. The floated materials are separated by conventional methods. Pronounced reductions in suspended solids have been accomplished on all pulp and paper mill wastes in the Kalamazoo River Valley by the use of predominantly sedimentation-type waste treatment units (110). For deinking mill wastes these reductions range from 55 to 94 per cent and from 80 to 95 per cent for board mill wastes.

Lea (75) reported on one of the ways in which fresh-water consumption has been held down through the re-use of surplus white water from the paper mill for hydraulic barking, thus saving an equivalent amount of fresh water for other purposes. This re-use also tends to concentrate waste materials in one location. The re-use system described in detail has worked out satisfactorily and is currently saving between 6 and 7 m.g.d. of fresh water.

The treatment plant for a speciality mill making electrical insulating speciality papers from kraft pulp and waste rope fiber was described by Aekerman (2). Based on laboratory studies, a large-scale plant has been designed consisting of lagoons or equalization basins, trickling filters, and secondary settling basins. Nutrient costs are expected to run $10 to $15 per day and pumping costs will be $9 per day. The cost of the installation and equipment will be $60,000.

*Semi-Chemical Process Effluents*

To recover chemicals from the neutral sulfite semi-chemical process, brown liquor is mixed with kraft liquor and subsequently processed as straight black liquor (11). The mixture is evaporated and burned in conventional kraft mill equipment. The recovery of neutral sulfite semi-chemical chemicals for re-use as kraft chemicals has resulted in a 30 per cent decrease in salt cake make-up and has accomplished a 90 per cent reduction in pollution load. Voights (141) discusses the experience of a semi-chemical mill in alleviating a serious pollution problem through the use of lagooning and subsequent spray disposal of spent cooking liquors from neutral sulfite semi-chemical pulping operations.

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## Tannery

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## Textile and Wool Scouring Wastes

Several investigators have determined the B.O.D. of various chemicals that may be employed in textile processing with the objective of economically replacing high-B.O.D. chemicals with those having a low B.O.D. Dickerson (41) compared the B.O.D. of starch with that of carboxymethyl cellulose (CMC) and found that a 0.1 per cent solution of starch gave a 5-day B.O.D. of 812 p.p.m., whereas an equivalent

strength solution of CMC gave a 5-day B.O.D. of 11 p.p.m. Investigations of mixtures of starch and CMC showed that the 5-day B.O.D. of the mixture was reduced directly as the starch content was reduced. CMC showed no bacteriostatic or toxic effect, although it retarded the exertion of the starch B.O.D. In actual plant studies, where a mixture of CMC and starch was employed, the 5-day B.O.D. was reduced 85 per cent from that of starch alone; although, on the basis of laboratory studies, a 65 per cent reduction would have been expected. Laboratory studies of trickling filter treatment of CMC, starch, and sewage revealed that CMC had no detrimental effect on the purification of municipal sewage. McCarthy (85) also reported the results of B.O.D. determinations of solutions of starch and starch substitutes. The results showed that practically all the substitutes had much lower B.O.D. values than equivalent strength starch solutions.

Masselli and Burford (83)(84) extensively reviewed the sources of textile wastes and reported B.O.D. values for many process chemicals. They recommended substitution of low-B.O.D. chemicals for those having high B.O.D. values. Some substitutes suggested were synthetic detergents for soaps; ammonium sulfate for acetic acid; carboxymethyl cellulose and hydroxymethyl cellulose for starch; polyvinyl alcohol, polyacrylic acid and styrene-base sizes for gelatin; and monochlorobenzene for o-phenyl phenol. The authors suggested that many other substitutes resistant to biological attack will be found with additional research.

McKinney (88) pointed out that the replacement of high-B.O.D. chemicals with chemicals resistant to biological attack may create even more difficult problems. The substitutes might encourage plant growth in receiving waters, create problems in water treatment, or be toxic to higher animals. McKinney also described a modified activated sludge process designed to treat wastes from desizing and caustic wash operations. The system employs endogenous respiration and thereby eliminates the need for sludge disposal. The B.O.D. of the waste treated was reduced from 368 p.p.m. to 10 p.p.m. by the process.

Souther and Alspaugh (130) reported the results obtained from the study of the biological treatment of a mixture of domestic sewage and alkaline textile wastes. The results show that waste mixtures with a pH as high as 11.5, a phenolpthalein alkalinity of 562 p.p.m. and a B.O.D. of 558 p.p.m. can be treated through high-rate filtration and activated sludge units. A total B.O.D. reduction in excess of 90 per cent was obtained through all units. Lesser degrees of treatment may be attained by increasing loadings, reducing the number of filters, or eliminating the activated sludge unit.

Laboratory experiments on the anaerobic digestion of sludge from viscose rayon manufacture were described by Meinck and Tomaschk (91). The results of the experiments showed that for satisfactory decomposition of viscose sludge by methane bacteria, pretreatment of the sludge is necessary. The authors recommended filtration for removal of most of the zinc, iron, and sodium sulfate; sludge washing for removal of the remaining toxic zinc salts; addition of lime for increasing alkalinity and precipitating zinc salts; addition of nutrient salts, such as ammonium sulfate and primary potassium phosphate; and careful maturing of the process by gradual, small increases in the daily addition of raw viscose sludge.

Fong and Lundgren (47) presented results of a laboratory study of the value of various coagulants as additives in the conventional acid cracking of wool scouring wastes. They found that a dispersible-type bentonite added to waste acidified to a pH level of 3 to 4

produced a marked improvement in grease removal. In the treatment of a typical wool scour waste, as much as 96 per cent of the grease was removed by the use of acid and bentonite as compared with a 67 per cent removal with acid alone. The C.O.D. of the waste was reduced approximately 60 per cent by the acid and bentonite treatment as compared with a 33 per cent reduction with acid alone. The amount of bentonite required depends on the grease and suint content of the waste, but normally is between 0.1 and 0.5 per cent.

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## RADIOACTIVITY

### Waste Sources

Since the functions of chemical processing are to separate the fissile and fertile fuels from the fission products, these operations are the major source of radioactive wastes. With the expansion of the nuclear power industry, it is felt that the presently accepted method of tank storage for such wastes will not be entirely satisfactory. Various schemes have been suggested for handling wastes resulting from a nuclear power industry (35)(94)(17)(36)(5)(44).

Lawroski (55) surveyed the separation processes employed and included in his study precipitation, ion exchange, fractional distillation, pyrometallurgy and solvent extraction processes. Nicholls (66) gave criteria for selection of separation processes. Detailed discussions of each of these processes have been presented: solvent extraction (19)(20)(29)(31)(32)(37)(39)(41)(69)(91); precipitation (29); ion exchange (29)(14); fractional distillation (50); high temperature processing (25)(65)(92); and pyroprocessing (28)(70). Rodger (74) discussed the trends in separation processes and their effects on waste handling.

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### Fixation of Wastes and Firing

The greatest amount of work on the "permanent" fixation of radioactive materials to clay, which is then converted to a ceramic by firing, has been carried out by Hatch and Regan (43).

Their recent investigations have extended this method to the treatment of high-level wastes. Because of the large amount of nitric acid or aluminum nitrate in the waste solutions, the wastes must be pretreated to avoid saturation of the montmorillonite clay with these cations. Permselective membranes were tried for this but, more recently, kiln drying of the aluminum nitrate-fission products waste to form aluminum oxide has been developed. The aluminum oxide, plus fission products, is leached and the leachate containing a fraction of the fission products is passed through montmorillonite clay. The clay columns are fired at temperatures up to 1,000° C. to fix the radioactivity permanently, and then disposed of by storage underground or other suitable means.

Amphlett and Warren (2)(3) investigated the use of natural silicate materials and soils as bases for adsorbing radioactive wastes. The mixture is fired at high temperatures to fix the radioactivity in an unleachable state in glass. The process is applied to slurries and solid wastes as well as solutions. Experimental results on required temperatures were given by Amphlett and Warren (4). Johnson *et al.* (51) concluded that liquid wastes containing between 100 and 1,000 c. (curies) per gallon may be placed in insulated concrete-lined earth pits and will self-heat to temperatures adequate to become fixed in clay-flux mixtures. The mixtures used in these experiments were developed by McVay, Hammer, and Haydon (62). They combined Conasauga shale, soda ash, and limestone with a simulated aluminum nitrate-nitric acid waste solution to form a ceramic mass at a temperature as low as 1,050° F. Studies at Los Alamos (89) showed that alpha activity in filter cake (4,000 c.p.m. per gram) and raffinate wastes (126,000 c.p.m. per milliliter) were fixed for safe disposal when fired with clay. Beta-gamma wastes at the 400 mc. (millicurie) level have not been satisfactorily fixed by this method. Additional studies are underway to determine the influence of such factors as clay mixtures, controlled firing, fluxes and glazes, and leaching solutions. Patrick (68) proposed a method of synthesizing aluminum silicates which eventually metamorphose to feldspatic structures with alkali or alkaline earth oxides. He is applying this method to the removal of strontium and cesium from high level wastes.

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## Liquid Wastes

Liquid waste sources may be divided into three broad classifications according to level of radioactivity: low, intermediate, and high. Low-level wastes (95) are those which, if decontaminated by a factor of 100 or 1,000, would approach permissible limits for human exposure. They range in radioactivity from $10^{-4}$ to $10^{-3}$ $\mu$c. per milliliter. High-level wastes are those requiring shielding and may contain 100 or more curies per liter. Intermediate wastes also require shielding and must be handled with considerable care. They may be: (a) high-level wastes which have lost a considerable fraction of their radioactivity as a result of decay; (b) residual wastes following recovery or separation of the useful isotopes; (c) wastes from pilot-plant operations; or (d) low-level wastes that have been concentrated by evaporation or other means.

The presently accepted method for handling high-level waste materials is storage. Granquist and Tomlinson (38) pointed out that, with a Purex-type of fuel-recovery process and mechanical dejacketing of the fuel elements, about 20,000 gal. of highly radioactive waste would be produced by irradiation of natural or slightly enriched uranium to about 2,500 megawatt-days per ton. The waste volume would be expected to self-boil, perhaps for 50 years. At Hanford, non-boiling wastes in 500,000 to 1,000,000 gal. tanks can be stored in reinforced concrete tanks with mild steel liners at a cost of $0.20 to $0.25 per gallon, and self-concentrating wastes may be stored at a cost of $0.40 to $0.50 per gallon of tank space. Since this cost amounts to only 0.01 to 0.05 mill per kilowatt of electrical power produced, they state (38) that there is no pressing economic need to develop a better system of waste handling.

Jonke (52) described a process for converting aqueous nuclear wastes to solid form by injection into a fluidized bed of heated solids, where evaporation and calcination of the waste to oxides is effected. Another calcining operation has been described by Hatch et al. (44) in which simulated highly radioactive waste streams containing salt were converted to anhydrous free-flowing melts.

At Hanford, Wash., (77) the waste disposal and control programs include confinement of high-level process wastes, cribbing of the low-level process wastes, burial of solid wastes, and discharge of reactor coolant water to the Columbia River. It was reported (76) that the concentration of alpha emitters in Columbia River water averaged less than $5 \times 10^{-9}$ $\mu$c. per milliliter at all locations, the average radioactive density of beta emitters approximated that reported previously, and the radioactivity of alpha emitters in mud samples was less than the detection limit of $3 \times 10^{-6}$ $\mu$c. per gram. The water quality characteristics of the Columbia River prior to impoundment and the effects of radioactivity released from Hanford on the physical, chemical, and biological characteristics of the stream were reported (46) and compared with similar data obtained by the General Electric Company.

In order to permit ground disposal of additional wastes at Hanford, several studies were made to separate strontium and cesium from process wastes. Schulz and McKenzie (79) reviewed chemical processes for the removal of strontium from wastes solutions and of cesium from mildly basic solutions, strongly alkaline solutions, and acidic wastes. Rimshaw (73) described the use of co-crystallization with ammonium alum for the recovery of kilocurie amounts of cesium. Strontium, ruthenium, and rare earths were precipitated in kilocurie amounts as hydroxides and carbonates on ferric hydroxide carrier. Experimental evidence indicated the feasibility of using these precipitation and crystallization methods to decontaminate radioactive wastes high in sodium or aluminum.

Specific studies for decontaminating aluminum waste solutions were described by Blanco, Higgins, and Kibbey (10). They utilized a scavenging precipitation and an aluminum-resin ion exchange technique. Gross beta-gamma decontamination factors of $10^3$ (influent over effluent radioactivity) were obtained with 97 to 99 per cent of the aluminum appearing in the eluate. The cesium and strontium decontamination factors were $10^3$ to $10^4$, respectively.

A further development was reported by Higgins and Wymer (48) who decontaminated an aluminum nitrate-nitric acid radioactive waste. Ninety per cent of the niobium and 95 per cent of the ruthenium and zirconium were removed by a ferric hydroxide-manganese dioxide scavenging precipitation. The aluminum nitrate was converted to a dibasic aluminum nitrate

by destructive distillation and dissolved by 12-hr. digestion at 160° C. The strontium, cesium, and rare earths were removed by cation exchange in a continuous contactor. The decontaminated waste can be volume-reduced to about 6M aluminum before disposal and then stored cheaply. The fission products can be eluted from the column, concentrated to a small volume of highly radioactive waste, and stored with all necessary precautions.

At Los Alamos (49), a radioactive waste containing $Ba^{140}$, $La^{140}$, $Sr^{90}$, and $Y^{90}$ was passed through a cation exchange resin column. Storage in the column results in the decay of short-lived barium and lanthanum isotopes. Within reasonable limits of raw waste quality, the ion exchanger reduces the $Sr^{90}$ concentration to permissible levels for discharge. The resin column was regenerated on exhaustion and the spent regenerant treated by chemical precipitation and vacuum filtration.

Laboratory work on second decontamination cycle wastes, using ferrous sulfide and ferrous ferrocyanide precipitation, have been described (56). The best results were obtained with ferrous sulfide as a precipitant in conjunction with an absorbant. A removal of 97.9 per cent of the radioactivity was possible with the ferrous ferrocyanide method and resulted in a low burial volume compared to the original waste volume. The radioactivity of the final supernatants could be maintained below 300 c.p.m. per milliliter. First cycle wastes could be decontaminated by repeated ferrous sulfide scavenging.

Another scheme reported by Glueckauf and Healy (36) for the separation of cesium and strontium involves the following: the fission products are taken to dryness to remove all nitric acid and water, the dry material is roasted for about an hour at 300° C., whereby all the nitrates except those of the alkali and alkaline earth metals are decomposed to oxides. The solid is then leached with warm water which dissolves the cesium and strontium nitrates, leaving behind all the water insoluble oxides. Usually about 95 per cent of the cesium and 85 per cent of the strontium can be extracted. The roasting temperature is rather critical. The separated strontium and cesium may be concentrated for separate storage and the residual fission products may be stored for a shorter time in separate facilities.

Krieger, Kahn, and Straub (53) described precipitation studies for the removal of strontium, cesium, zirconium, niobium, yttrium, ruthenium, and cerium from simulated high-level aluminum nitrate wastes. The separation of the waste into such components with separate storage of the more hazardous fraction has advantages in that less storage space will have to be provided, less elaborate storage may be provided for the bulk of the wastes, self-boiling of the waste will not take place, and there will be no need for special tank cooling facilities.

The induced radioactivity levels reached in cooling waters have been described by Farmer (27) and Lyon and Reynolds (57).

The use of the electrodialytic method for the treatment of radioactive waste was studied on a laboratory scale by Seal and Pecsok (80). They reported that the method may be used to concentrate extremely dilute ionic constituents. Concentration factors of 100 to 1 were obtained with normal surface waters.

In the case in which the reactor burnup is 5,000 megawattdays (heat) per ton, the processing volume is 1,200 gal. per ton, and the allocated cost for waste disposal is 2 per cent (or 0.16 mills per killowatt hour), the allowable cost of waste disposal was estimated to be $4.00 per gallon by Zeitlin (97). The economic future of fission products for radiation power was discussed by Manowitz and Richman (58).

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## Ocean Disposal

The first studies relating to the possible utilization of the oceans for the disposal of radioactive wastes were conducted in the Irish Sea at Seascale, England, by the British. These studies (81) (24) (30) (8) (96) indicated that such disposal was feasible, providing continuous monitoring was maintained. Tests made on seaweed, fish, and seabed mud over a five-year period have shown no harm to marine or human life from the discharge of these relatively low-level liquid wastes.

Wolman and Gorman (94) report that costs for packaging, handling, and disposal of wastes at sea vary from a low of about $0.30 per pound along the east coast, to $0.80 to $1.00 per pound for waste along the west coast. Approximately 20 to 30 tons per year are disposed along the east coast as compared to about 4 to 5 tons on the west coast. No disposal of high-level wastes is practiced at present, but the oceanographic problems associated with disposal of high-level wastes was discussed by Renn (71)(72). In describing the Brookhaven experience with ocean disposal, Gemmell (33) reports that about 660 drums of waste totalling 600 c. were dumped at a cost of $20.00 per drum exclusive of overhead. North American Aviation (54) ships its stored wastes to sea at a cost of approximately $0.71 per gallon based on 100 55-gal. drums per dumping. Dumping takes place some 60 miles off the coast of Southern California at a depth greater than 800 fathoms.

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### Ground Disposal

Before burial of radioactive materials, the geology and the hydrology of the particular disposal site must be well understood. The hydrological and geological factors affecting ground disposal at Hanford, Wash., Brookhaven, N. Y., Oak Ridge, Tenn., Idaho Falls, Ida., and Savannah, Ga., were discussed by Brown *et al.* (12), deLaguna (21), and Theis (87). Theis (88) also described the general types of formations useful for ground disposal. These include: (a) sandy, relatively permeable formations, (b) permeable cavernous formations, (c) jointed or otherwise fractured rocks, (d) relatively impermeable shales, or (e) deposits of salines (rock salt or gypsum). Thurston (90) points out that many geological principles and methods used in the petroleum industry are applicable to radioactive waste disposal. The preparation of artificial cavities in salt and shale for the storage of hydrocarbons may be adaptable to the shallow underground disposal of a comparable volume of radioactive wastes. Furthermore, the natural porosity of many sedimentary rocks may be suitable as reservoirs for the safe disposal of wastes at great depths.

The reactions of radioisotope solutions with the soils at Hanford, Wash., were described by McHenry, Rhodes, and Rowe (61) with respect to the effects of concentration, pH, total ion concentration, and the type of soil. A significant increase in strontium adsorption in the presence of phosphate ion is shown to counteract the adverse effect of high salt concentrations. Experimental evidence and theoretical considerations illustrate the low diffusion rate of strontium. Preliminary investigations were carried out by Orcutt *et al.* (67) on the feasibility of high-level radioactive waste disposal by injection into isolated geological formations. Density effects and exchange reactions between the simulated strontium wastes and columns of clay or oil sand were studied. They observed that exchange reactions may retard the advance of radiostrontium concentration fronts to as much as 1/40 that of the liquid fronts.

Ground disposal has been practiced at several sites including Hanford, Wash., Oak Ridge, Tenn., and Savannah, Ga. At Hanford (13), approximately $10^9$ liters of active wastes containing several hundred thousand curies of fission products have been stored in the ground during the first

decade of operation. During three years of operation, approximately 2.7 million gal. of waste containing 35,000 c. of radioactivity were placed in surface pits scooped in the surface Conasauga shale formations at Oak Ridge, Tenn. (86)(93). Clark and Pohl (16) report that 130,000 gal. of wastes are discharged daily into soil at Savannah. With a basin life of three years it is estimated that the cost of disposal amounts to $0.001 per original gallon. The experiences at Chalk River, England, in disposing of its wastes into the ground have been described by Mawson (59).

The construction of an experimental asphalt-lined pit for testing its practicability for disposal of high-level radioactive processing wastes was described (18). Final results indicated losses up to 22 gal. per day which were attributable to non-uniformity in asphalt liner thickness and tamped shale puncture.

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## Non-Radioactive Wastes

Not all wastes produced by the nuclear energy industry are radioactive. Where acid dissolution of partially spent fuel materials is practiced, large quantities of nitrate wastes will result. Christenson *et al.* (15) have developed a non-aerated activated sludge process which has a maximum rate of nitrate reduction in the order of 70 p.p.m. per hour. Their feed, based on a 6-l. feed volume, is 600 p.p.m. methanol, 250 p.p.m. nitrate nitrogen and 10 p.p.m. $PO_4$. This mixture is reduced in the 8-hr. contact time to 0 p.p.m. of nitrogen; about 40 p.p.m. of oxygen is consumed.

Liquid wastes from the production of hafnium-free zirconium contain 1.8 lb. of ammonia per pound of zirconium produced, along with trace amounts of cyanides, thiocyanates, sulfates, and chlorides. McDermott (60) indicated that the process wastes which are most objectionable from the pollution standpoint amount to 10 gal. of concentrated ammoniacal waste per pound of zirconium produced. The waste is held in basins before trucking to a large river for disposal by dilution.

In the uranium and thorium refining and reduction operations, large quantities of fluoride containing wastes are produced and recovered according to Heatherton (45). The solid fluorides are disposed of by dumping in a pit at a cost of $0.54 per cubic foot. Liquid wastes are released in such a manner that the fluoride content of the stream does not exceed 1.2 p.p.m. (background fluoride level of stream being 0.4 p.p.m.).

## Low-Level Radioactivity

During the 1955 continental series of nuclear tests, samples from 20 municipal water treatment plants were examined to determine the extent of removal of fall-out material by large-scale treatment plants. Eliassen and Lauderdale (26) have summarized the procedures used and have reported the data obtained in analyzing the Lexington, Ky., samples. They state that: (a) detectable amounts of fall-out occur in water supplies only after rainfall; (b) increased amounts of turbidity in the water do not result in an increase in per cent reduction in radioactivity; (c) the reduction in radioactivity appears to decrease with increasing age of the fall-out material; and (d) small quantities of radioactivity will persist in water supplies, particularly if impounded, for considerable periods after detonation of a nuclear weapon.

The Army engineers (9) have a mobile unit which will decontaminate 3,000, 1,500 or 600 gal. per hour of suspended or dissolved radioactivity by a factor of $10^3$ (99.9 per cent reduction).

Data have been released (11) reporting the results of studies made in 1949 on the uranium content of the sludges at the two sewage treatment plants serving Oak Ridge, Tenn. The sludge produced at the West plant was reported to contain 25 to 50 p.p.m. of uranium, and that at the East plant, 5 to 10 p.p.m. At the time of the tests some wastes from the plant areas were discharging to the West plant, thus accounting for the higher uranium values.

Single- or two-stage trickling filters (23), operated continuously at organic loadings of 250 lb. of B.O.D. per acre-foot per day, removed about 90 per cent of gross fission product from laundry wastes. Increased loadings resulted in lower removal efficiencies. Sludge was produced at a rate of about 0.3 lb. of dry solids per pound of B.O.D. removed. The radioactivity level reached in the sludge was a function of the initial radioactivity level. Removals of individual radionuclides were as follows: cesium, 97.3 per cent; rubidium, 79.1 per cent; strontium, 69.4 per cent; iodine, 86.7 per cent; zirconium-niobium, 79.5 per cent.

Hermann and Gloyna (47) report that oxidation ponds may be designed to concentrate, delay, and possibly remove many bothersome radioisotopes that may be in a waste stream, especially when the concentration of radioactivity is near the maximum permissible concentration. Intermittent "slug" batches of radioactive isotopes, if in low-level amounts, are diluted, and in many cases removed by the relatively long detention periods utilized in oxidation ponds. More specifically the authors conclude that: (a) algal-bacterial populations are more efficient than bacterial suspensions in detaining phosphorus $^{32}$ for decay purposes; (b) about 95 per cent or more of the cerium may be removed; (c) about 80 per cent of aged fission products are retained in oxidation pond suspensions or bottom sediments; (d) about 33 per cent of the strontium may be removed, but removal may be enhanced by continuous removal of algal suspended particles; (e) algae are not effective for the removal of iodine and cesium; (f) the contaminated algae and other suspended matter can be effectively removed by vacuum filtration; and (g) oxidation ponds are not feasible for concentrating high-level radioactive wastes.

Guchi, Norimitsu, and Yauchiro (40) reported laboratory studies on the uptake of radioactivity by algae from brackish water containing 0.2 $\mu$c. per liter of mixed fission products. A culture of two organisms (*Aphanocapsa koordersii* and *Brachionus*) effected an over-all removal of one-half to two-thirds of the radioactivity in six days. Radiochemical analysis indicated about one-half of the uptake consisted of rare earth elements and about 15 per cent was strontium and yttrium. After 12 days the settled dead *Brachionus* had decomposed and released to solution part of the adsorbed radioactivity.

In considering the criteria for waste disposal Straub (85) proposed that these be established on the basis of stream use (water supply, recreation, game fishing, irrigation, and industrial use).

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## Burial—Solid Wastes

Five national burial sites (located at: the Hanford Works, Wash.; National Reactor Testing Station, Ida.; Los Alamos Scientific Laboratory, N. M.; Oak Ridge National Laboratory, Tenn.; and Savannah River Project, Ga.) are operated by the U. S. Atomic Energy Commission for the disposal of solid wastes (64). The physical factors affecting the desirability of any particular site are topography and geology, surface and ground water hydrology, meteorology, soil conditions, and transportation facilities. From results reported by Morgan (64) the costs of operating such disposal sites ranged from $1.52 to $9.40 per cubic yard of material. These costs did not include sample containers and processing and handling at source, but only capital and operating costs at the site, and may be compared with specific costs at given sites. At Oak Ridge the annual burial load amounts to about five acres per year at a cost of approximately $2.00 per cubic yard (1). At the National Reactor Testing Station (7) approximately 3,800 cu. yd. of solid wastes have been disposed of since 1952 from Rocky Flats, Colo., at a reported cost exclusive of packaging and handling of $21.00 to $35.00 per cubic yard (78).

Experience in the demolition and burial of an alpha contaminated building (48,000 sq. ft. in area) was described by Meyer (63); the cost of such an operation being five-fold greater than that of demolishing a non-contaminated building.

## Incineration

The results of three experiments (42), involving the burning of combustible materials under widely varying conditions and using greatly different quantities of waste, indicate no significant contamination either of the soil or of the air. If incineration of this type is carried on with a frequency dictated by the scope of operation, it should be possible to consume all of the combustible waste materials in this manner, and thereby significantly reduce the volume and weight of materials for final disposal.

Studies to evaluate the effect of incinerating waste materials containing $P^{32}$, $Sr^{89}$, and $I^{131}$ in an institutional incinerator are reported by Geyer *et al.* (34). The results indicate that of the $P^{32}$ charged into the incinerator, about 12 per cent was retained on the stack wall and 2 per cent was recovered from the stack gas. Of the $Sr^{89}$, 9 per cent was retained on the wall and 1 per cent was recovered in the gas. Of the $I^{131}$, about 11 per cent was deposited on the wall and 80 per cent escaped in the gas. The radioactivity of the ash

was assumed to be the balance of the charge.

The use of a Martin Burn-All Incinerator has been described by Silverman and Dickey (83) for reduction of combustibles contaminated with low-level amounts of radioisotopes. Maximum daily load is set at 200 $\mu$c. for all isotopes except $I^{131}$ which is set at 500 $\mu$c. The stack gas effluents had activity levels of $7 \times 10^{-11}$ $\mu$c. per milliliter. Maintenance over a two-year period of operation (3,400 lb. of assorted combustibles containing 27,100 $\mu$c. of radioactivity) were handled at a cost of less than $1.00 per month.

Rodger and Hampson (75) reported operating data on the incinerator designed and built at Argonne National Laboratory to handle 100 cu. ft of combustibles daily. Over-all decontamination factor (ratio of influent feed to effluent gas concentration) was 2 to 3 $\times 10^7$. Cost of incineration amounted to $2.68 per cubic foot for 8-hr. operation and $1.60 per cubic foot for 24-hr. operation, as compared with solid storage costs of $9.00 per cubic foot. At present, the combustibles are being shipped to Oak Ridge, Tenn., for burial at a cost of $1.50 per cubic foot, thus removing the economic justification for incineration.

### Gaseous and Airborne Wastes

Air and gas cleaning for nuclear engineering processes was discussed by Silverman (82). The problems associated with the handling, metallurgy, reactions, and applications of nuclear energy processes are described along with the cleaning requirements for protection of personnel in these operations. Special emphasis was given to the aspects of cleaning gases from power reactors. Performance data are included for various devices on radioactive and inert aerosols encountered in mining, feed materials, production, metallurgical reactions, reactor operations, isotope production and handling, and special problems, such as incineration of contaminated waste materials. Mention is made of recently developed methods of gas cleaning, such as high-temperature and corrosion-resistant filtration media.

Investigations on the principles of cloth filtration, on the role of electrostatic forces in gas cleaning, and on the resistance and filtration characteristics of filter beds were described by Dennis *et al.* (22). New projects included the rating of several types of roughing filters, evaluation and testing of stain efficiency techniques, and a study of blast damages to and reentrainment from high efficiency filters.

The results of a laboratory investigation (6) for removing radioactive particulate matter entrained in gas streams indicates that, by the use of steam injection technique, removal efficiencies approaching those obtained with a CWS-6 filter paper and can filters can be realized in a commercial wet impingement plate scrubber operating on a nonradioactive dust suspension approximating actual plant conditions. Operating the scrubber alone proved unsatisfactory. Sonic agglomeration improved efficiency of the wet scrubber. Methods were developed for generating and analyzing both radioactive and nonradioactive airborne particulate matter. They were applied successfully to the evaluation of various filter papers and a pilot-plant gas-cleaning system.

Smith (84) described the extensive experiments carried out at Brookhaven National Laboratory, N. Y., to define dispersion patterns. The quantitative data, though incomplete, suffice to show that an orderly gradation of dispersion conditions exists, and that a generally acceptable prediction of the ground-level concentrations can be achieved during lapse conditions. The qualitative measurements made under inversions indicate that concentrations can be predicted in this case also. The gustiness classification needs consider-

able improvement. The most suitable type of field sampling includes a large number of accurate devices operated simultaneously. The importance of time is stressed, and from the wide variation observed any field experiment will be a function of time, at least up to periods of 1 hr.

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# Sewage Works

## SYNDETS AND WASTE DISPOSAL

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One of the most intriguing and challenging problems to face sanitary engineers is that of the disposal of synthetic detergents, better known as syndets. No topic of conversation is more controversial than the effect of syndets upon water treatment systems and upon sewage treatment systems.

To the operator and the engineer, syndets are the cause of all of the current treatment plant operational problems. The syndet manufacturers are equally convinced that syndets are being blamed unjustly for all of the operational aches and pains. As a result of all of this controversy syndets has become the "hottest" research topic in the sanitary engineering field.

The U. S. Public Health Service, through the staff at the Robert A. Taft Sanitary Engineering Center and through the National Institutes of Health Research Grants, has encouraged much of the research on syndets. The American Soap and Glycerine Producers Association has also undertaken major research efforts not only with the staffs of member companies but also with projects at four of the major universities teaching sanitary engineering.

In spite of all of the research which has gone on and is still continuing, the exact effect of syndets on water treatment systems and sewage purification plants has not been fully delineated. The major results of the syndet research point only to the complexity of the problem and the need for careful evaluation of all of the data before blaming or exonerating syndets for the current treatment problems.

Much has been published about the syndet problems both pro and con. It is possible to derive enough information from the literature to completely exonerate syndets of all blame or to completely condemn syndets for everything. This paper does not attempt to exonerate or to condemn syndets, but rather attempts to set forth all of the facts that are available so that each person may draw his own conclusions.

### Nature of Syndets

To the housewife syndets are one of the most important contributions of chemistry to the modern way of living. Syndets make washing dishes and clothes an easier task and produce cleaner results than soaps. Basically, syndets and soaps are similar in general structure, both hydrocarbons with a hydrophilic end and a hydrophobic end to the molecules. The hydrophilic (water attracting) end of the soap molecule is a carboxyl group, —COOH; the hydrophobic (water repelling) end is a long straight chain hydrocarbon.

The earliest syndets merely substituted a sulfate group, $SO_4^=$, for the carboxyl group. But the present syndets have many different chemical groups that impart hydrophilic and hydrophobic properties to the molecule. The hydrophobic portion of the syndet is readily attracted to suspended organic matter in the liquid. The hydrophilic portion of the molecules remains

exposed and tends to hold the organic particles in suspension. The fact that syndets are not readily precipitated by calcium and magnesium makes them more desirable than soaps, which are precipitated.

The first references to syndets were made as though all syndets were of similar chemical structure. As research developed, it was found that syndets could be classified according to the type of ionization of the molecule. Those syndets which were ionized to give a negatively charged molecule in water were called anionic; those which ionized to a positively charged molecule were called cationic. The syndets which did not ionize to yield charged molecules were all classified as nonionic. This is the simplest type of syndet classification and is the one which has persisted through most of the literature to this time.

But ionic classification does not give the entire picture. The syndets in each ionic group can be broken down still further to basic chemical structures. It will be shown later that classification to basic chemical structures is the key to the syndet problem as far as sewage disposal is concerned.

*Chemical Classifications*

The anionic syndets can be broken down into the following chemical classifications:

1. Alkyl benzene sulfonates (ABS).
2. Normal fatty alcohol sulfates.
3. Secondary fatty alcohol sulfates.
4. Esters of sulfosuccinic acid.
5. Sulfated ethanol amides.
6. Sulfated monoglycerides.
7. Miscellaneous petroleum sulfonates.

The cationic syndets belong primarily to the quaternary ammonium compounds. The nonionics are like the anionic syndets and have varied structures. Unlike the anionic syndets the nonionic syndets have a basic component, ethylene oxide. The ethylene oxide molecules are condensed to form polymers of various lengths and are joined with the following chemical compounds to form the nonionic syndet:

1. Fatty acids.
2. Fatty alcohols.
3. Alkyl phenols.
4. Fatty acid amides.
5. Fatty amines.

Within each of these chemical classifications there are varied chemical compounds. Thus, the syndet problem is not just one of a single molecule or a single type compound, but rather is a complex problem dealing with tens and even hundreds of different chemical structures, none of which were common to nature prior to development of synthetic detergents.

*Syndet Production*

Although the syndet problem looks expansive at first glance, it is not as complex as it seems. There are many different chemical structures of syndets; but all of these structures are not being produced and marketed in equal quantities. Syndet production (1) gives a clue as to what structures are going to be important and how large this problem is going to be. In 1954, there were 2.5 billion pounds of syndets produced. It is estimated that 3.5 billion pounds will be produced in 1962. Approximately 80 per cent of the total syndet production is for household-type detergents.

The anionic syndets are the most popular syndets,—80 per cent of total syndet production. Within the anionic syndets the alkyl benzene sulfonates account for 60 per cent; the fatty alcohol sulfates make up 30 per cent and all of the remaining types make up the remaining 10 per cent.

The cationic syndets have only 1.0 per cent of the total production. The cationic syndets are specialty syndets designed primarily for their bactericidal action and are used where a sani-

tizing syndet is desired. The nonionics make up 19 per cent of the total syndet production. It is doubtful if there will be too much change in these production ratios during the next few years. The nonionics appear to be on the increase and the fatty alcohol sulfates appear to be on the decrease.

*Syndet Formulation*

It is therefore possible to reduce the syndet problem to the alkyl benzene sulfonates, the fatty alcohol sulfates, and the nonionics, with ethylene oxide condensations. These are the surface active fractions in syndets; but there are more compounds than just the surface active agent in commercial syndets. The other compounds in commercial syndets are referred to as builders. The builders are various chemical compounds added to the syndet to increase its effectiveness. The most common builders include complex phosphates, sodium sulfate, carboxymethyl cellulose, silicates, and sodium carbonate.

The builders vary from product to product. There is no set formula for syndets, but it is possible to set a relative proportion for illustration purposes. A commercial anionic syndet of the alkyl benzene sulfonate type (2) is 30 per cent alkyl benzene sulfonate, 28 per cent polyphosphate, 6 per cent sodium silicate, 35 per cent sodium sulfate, and 1 per cent carboxymethyl cellulose. Note that the sodium carbonate has been left out of this formulation. Some commercial products will have sodium carbonate to aid pH control. Thus, it can be seen that syndets are not just surface active materials and that any problem related to the syndets must include the builders, as well as the surface active agent.

## Syndet Problem

It has been only within the past decade that syndets have become a major constituent of sewage. In 1945 (3), when 150 million pounds of syndets were manufactured, syndets accounted for less than 10 per cent of the total soap and syndet production. By 1947, when the first indication of frothing in a sewage treatment plant might be related to syndets, syndet production had increased almost threefold to 420 million pounds. By 1951 the production of syndets had become 10-fold at 1.5 billion pounds. As already indicated, the 1954 production was 2.5 billion pounds and the estimated 1962 production will be 3.5 billion pounds. Syndets are rapidly replacing soaps in sewage and the tendency will increase.

Never has the sanitary engineer been faced with such a drastic change in the chemical nature of sewage. The advent of garbage grinders did not result in as drastic a change in sewage composition as has the increased use of syndets. Many problems of sewage and water treatment plant operation have occurred at the same time that syndets became popular, and syndets have been blamed for them all.

Some of the problems indicated in sewage treatment plant operation have been frothing in aeration tanks and outfall lines, reduced efficiency of primary sedimentation devices, reduced efficiency of secondary treatment units, and lower gas yields in digesters. The water treatment problems have included poor flocculation and sedimentation, tastes and odors, reduced filter runs, and frothing of the finished water.

In part, the water treatment problems and the sewage treatment problems are related to one another, for the water problems exist only where sewage effluent is discharged to the watercourse supplying the water for treatment. Thus, the problem starts in the sewage treatment plant, passes to the receiving body of water and then to the water treatment plant. That is, if there really is a syndet problem.

## Sewage Treatment

Frothing at the sewage treatment plant at Mt. Penn, Pa., in 1947 (4) was the first report of troubles that were to come. In the summer of 1949, frothing became a serious problem at the activated sludge plant at Batavia, Ill. (5). Although it was impossible to determine the cause of the frothing, suspicion was placed on the syndets used in a milk processing plant.

As it became evident that syndets were going to constitute a greater part of sewage, researchers turned to the laboratory to determine what effect these syndets might have on sewage treatment practices. In 1949, Rudolfs *et al.* (6) reported on their first studies, which indicated that syndets would reduce sewage solids settleability slightly, reduce grease removal in the primary sedimentation tanks, reduce gas production as a result of reducing the quantity of solids, and affect activated sludge by causing frothing, floc agglomeration, and floc carryover from the sedimentation unit.

### *Alkyl Sulfates*

In Europe the primary syndets were alkyl sulfates. Waddams (7) found that sodium secondary alkyl sulfate was not toxic to *Escherichia coli* or to *Bacillus proteus* in concentrations up to 100 mg. per liter. The addition of 20 mg. per liter of sodium secondary alkyl sulfate to sewage caused a 50 per cent increase in B.O.D. of the sewage. Degens *et al.* (8) studied the effect of sodium primary alkyl sulfate and of sodium secondary alkyl sulfate on the exertion of B.O.D. of domestic sewage. Sodium primary alkyl sulfate and sodium secondary alkyl sulfate not only did not reduce the sewage B.O.D. in concentrations up to 100 mg. per liter, but also exerted a B.O.D. of their own. The primary alkyl sulfate was immediately metabolized, whereas the secondary alkyl sulfate exerted a slight lag for one to two days but still exerted a greater 5-day B.O.D. than the control.

These first studies showed that the alkyl sulfates were metabolized biologically and would not cause any special problems in sewage treatment systems. Hurley (9) followed up these studies on the secondary alkyl sulfates and showed that these syndets did not cause any problem in trickling filters up to 150 mg. per liter concentration and in activated sludge up to 125 mg. per liter.

These data did not correlate well with the studies of Sperry (10) at Aurora, Ill. Data showed that in 1949 Aurora was sold on detergents in a big way. From sales records it was estimated that the detergent concentration during average dry weather flow was 45 mg. per liter. Treatment plant data indicated decreased 5-day B.O.D. removals and suspended solids removals in the primary sedimentation units. There was also a reduction in total gas production.

If syndets were all alkyl sulfates, it would have been hard to reconcile the treatment problems with the laboratory studies. But syndets in this country were basically alkyl sulfates and alkyl benzene sulfonates. Manganelli (11) investigated some of the commercial types of alkyl sulfates and alkyl benzene sulfonates. The alkyl sulfate in Dreft was readily oxidized in concentrations up to 1,000 mg. per liter, whereas the alkyl benzene sulfonate in Nacconol NR interfered with sewage oxidation in concentrations greater than 100 mg. per liter. Examination of toxicity of Nacconol NR to coliform bacteria in sewage indicated that there was no toxicity up to 100 mg. per liter. In activated sludge, 100 mg. per liter Nacconol NR retarded oxidation of sewage but had no effect on digestion of sewage sludge. Fifty milligrams per liter of the alkyl benzene sulfonate lowered the rate of oxygen transfer by bubble aeration in distilled water, but not as much as 50

mg. per liter of soap. From this it was concluded that at normal syndet concentrations in sewage, approximately one-half the concentration used in these studies, there would be only a slight effect on sewage treatment systems.

The question of the effect of syndets on septic tanks was studied by Fuller (12). He concluded that anionic syndets in concentrations up to 100 mg. per liter would not have an adverse effect on septic tank operations.

*Frothing*

Frothing in activated sludge systems became more frequent and it soon was the symbol of syndet problems. Donaldson (13) collected some of the aeration tank froth and condensed it for analysis. The froth contained 7,700 mg. of total solids, 1,800 mg. of grease, and 900 mg. of alcohol soluble detergent per liter of condensed froth. Spray nozzles were installed along the aeration tank to suppress the froth.

Stevens (14) advocated the use of antifoam chemicals for controlling froth. Petroleum defoamers were effective in concentrations of 0.5 and 1.5 mg. per liter.

Wells and Scherer (15) found that the frothing at the San Antonio, Texas, activated sludge plant could be controlled by maintaining the suspended solids above 1,400 mg. per liter in the mixed liquor. Lowering the suspended solids below 1,400 mg. per liter always resulted in excessive frothing. The San Antonio plant was ideally laid out for large-scale research, as the aeration tanks were divided into two sections. One section had the old-fashioned plate-type air diffusers and the new section had swing diffusers. Both sections were divided into a series of tanks all operating in parallel but fed from a common line. It was possible to adjust the suspended solids to any desired level in any one tank. With the aid of the Procter and Gamble Company, a study was made on the addition of Tide to the aeration tank. Tide was a mixed alkyl sulfate and alkyl benzene sulfonate. The syndet was added to the aeration tank in concentrations up to 250 mg. per liter without creating froth. This study has become the classic defense of those who feel that syndets are not responsible for frothing in aeration tanks.

The Procter and Gamble Company followed up the study at San Antonio, Texas, with one on a mechanical activated sludge plant at Bryan, Ohio (16). The investigation was made on Monday so that the sewage would contain the maximum syndet concentration in addition to the 100 mg. per liter syndet which was being added. This activated sludge unit normally operated at 800 mg. per liter suspended solids without frothing. The additional syndets did not cause frothing but frothing could be induced by lowering the suspended solids in the mixed liquor to 200 mg. per liter. It was felt that the frothing agent was not a syndet but was actually being manufactured in the aeration tank by the microorganisms.

This concept was backed by Martin (17) who indicated that frothing had been common in San Francisco, Calif., in 1932, before syndets were in use. Frothing was always greatest at the outlet end of the tank, the same as it was in almost all frothing cases reported due to syndets. Low suspended solids were responsible for frothing at the San Francisco activated sludge plant and raising the suspended solids in the aeration tank was the best control. Sprays and antifroth chemicals could also be used to control froth. Martin believed that frothing was a combination of surface active agents formed by biological action in the aeration tank and those present in sewage.

Degens (4) did not go along with the biological production concept for frothing. He believed that syndets were basically responsible for frothing. Frothing was due to persistence of syn-

dets in the aeration tank. The alkyl sulfates, which were readily metabolized in the aeration tank, were not considered to be problem frothers as were the alkyl benzene sulfonates, which were not readily metabolized. He, too, indicated that the three solutions to frothing lay in suspended solids control, sprays, and defrothers.

Syndets were believed responsible for frothing at a new activated sludge plant in Michigan (18). Examination of the raw sewage and the treated effluent indicated 8.0 mg. of syndet per liter. The froth was controlled by a spray system. The syndet did not affect treatment plant efficiency.

The first extensive laboratory studies of frothing by commercial syndets were carried out by Lynch and Sawyer (19). They studied the frothing characteristics of 50 mg. per liter of commercial syndets in Cambridge, Mass., tap water. There was no pattern of frothers or degree of frothing. Some syndets frothed very easily, others not at all. One of the weak frothers was Tide, which had been used in the San Antonio, Texas, studies. It was concluded that the San Antonio study did not give a true picture of a frothing syndet and was therefore invalid as far as syndet frothing was concerned. But it did indicate that it was possible to have nonfrothing syndets, as well as frothing syndets.

Examination of the rates of oxygen transfer for the various commercial syndets in Cambridge, Mass., tap water showed that there was considerable variation among syndets. The oxygen transfer coefficient was reduced up to a factor of one-third. It was believed that this could be responsible for increased air requirements in activated sludge plants since the advent of syndets. Eckenfelder (20) has shown that organic matter reduces the oxygen transfer coefficient over that of pure water quite materially. It becomes apparent that biological degradation of organic matter will play a major role in the persistence of the lowered oxygen transfer coefficient.

Further laboratory studies by Bogan and Sawyer (21) on activated sludge frothing in the presence of syndets indicated that there was a relationship between chemical constitution and frothing. Fifty milligrams per liter of syndets were used to show that the froth persistence dissipated in relationship to syndet metabolism. The poorly metabolized syndets frothed five days after feeding to activated sludge.

The addition of 25 mg. per liter of soap to the system completely tied up the syndet and prevented frothing until the soap had been metabolized. The tying up of the syndets by soap could explain the lack of frothing at the inlet of aeration tanks and its appearance at the end of the aeration tank, especially with the biologically resistant syndets.

*Change in Sewage Characteristics*

Other effects than frothing have been ascribed to syndets in sewage treatment plant operation. It was reported at Washington, D. C. (22), that replacement of soaps with syndets had resulted in a drop in the B.O.D. of the raw sewage. There was also a reported reduction in the efficiency of B.O.D. and suspended solids removals in primary sedimentation.

Thomas (23) showed that syndets had caused a definite change in the characteristics of sewage from military installations. The syndets resulted in lowering the B.O.D. value 5 to 15 per cent and the suspended solids content 5 to 10 per cent. In part, this depended on the type of detergent used.

Primary treatment was also affected, with as much as 60 per cent lower efficiency in grease removal and 20 to 35 per cent lower B.O.D. removal. The syndets held the grease in suspension and prevented its separation in the primary treatment device, and as a result the organic load was carried over to the secondary treatment devices. Sub-

stitution of syndets for soaps removed a portion of the B.O.D. load normally removed in primary sedimentation by the insoluble calcium soaps.

Degens *et al.* (24) found that Teepol, an alkyl sulfate, and Lissapol N, a nonionic polyglycol ether of an alkylated phenol, did not have an adverse effect on the sedimentation of raw sewage solids in syndet concentrations of 25 to 75 mg. per liter.

*Effect on Microorganisms*

The effect of syndets on sewage treatment seemed to hinge more and more on the action of the microorganisms upon the syndets. Manganelli and Crosby (25) studied the effect of Nacconol NR, an alkyl benzene sulfonate, on sewage microorganisms.

Submerging glass slides into sewage resulted in a buildup of slime growths on the slides. Addition of syndet to sewage in varying concentrations resulted in an increased slime mass over the control for syndet concentrations up to 50 mg. per liter. There was a slight decrease in mass at 100 mg. of syndet per liter.

Feeding 100 mg. per liter of syndet in sewage to activated sludge resulted in reduced oxidation of the sewage, loss of its nitrifying ability, increased turbidity of the treated effluent, and destruction of the protozoa. The only problem with this study was the fact that 100 mg. per liter of "active matter" was far in excess of that existing in sewage and probably in excess of the maximum concentration that will ever exist in sewage.

The 5-day B.O.D. test has long been used as a measure of biological degradation of organic matter. Bogan and Sawyer (26) found that the normal sewage seed gave a 5-day B.O.D. of 61.5 per cent theoretical for Dupanol C, an alkyl sulfate, and from 0 to 9.9 per cent theoretical for six commercial alkyl benzene sulfonates. Using activated sludge which had been acclimated to the commercial alkyl benzene sulfonates as the seed, the 5-day B.O.D. was 65.5 per cent theoretical oxidation; the 5-day B.O.D. of the alkyl benzene sulfonates ranged from 4.6 to 33.8 per cent. Warburg respirometer studies on the acclimated activated sludges and the pure syndets gave 45.2 per cent theoretical oxidation for the alkyl sulfate in 6 hr. and from 5.4 to 11.8 per cent theoretical oxidation for the alkyl benzene sulfonates. Sheets and Malaney (27) confirmed the B.O.D. data obtained by Bogan and Sawyer.

Degens *et al.* (28) investigated sodium secondary alkyl sulfate and alkyl benzene sulfonate and their effects on a continuous flow activated sludge system stabilizing sewage. The addition of 50 mg. per liter of sodium secondary alkyl sulfate to sewage caused a slight retardation of B.O.D. removal initially, but the microorganism quickly adapted to the syndet and gave complete stabilization. Feeding 30 mg. per liter of the alkyl benzene sulfonate resulted in retarded B.O.D. removals for the entire four weeks of the study. At the end of the four weeks of continuous feeding there was still 19 mg. per liter of alkyl benzene sulfonate in the effluent.

Reducing the syndet concentration to 12.5 mg. per liter still gave retarded B.O.D. removals, but lowering the syndet concentration to 5.0 mg. per liter showed no adverse effects on purification. It was found that the critical syndet concentration was related to the suspended solids content in the aeration system. No adverse effects were noted on purification where the syndet concentration was kept at or below 0.4 per cent of the dry weight of the activated sludge. For 2,000 mg. per liter of suspended solids, 8 mg. per liter of alkyl benzene sulfonate would be the maximum level of syndet allowed for complete stabilization.

Bogan *et al.* (29)(30) showed that the biological degradation of syndets was a function of their chemical struc-

ture. The hydrophobic alkyl group of the alkyl benzene sulfonates and the hydrophilic polyethylene oxide groups in the nonionics were the key chemical groups affecting biological metabolism. The degree of branching of the alkyl group of the alkyl benzene sulfonates was related to the resistance to biological metabolism, the greater the alkyl branching the more resistant to metabolism. This concurred with the views of Hammerton (31), who carried out extensive research on the metabolism of various branched alkyl structures by the microorganisms in natural water.

During a trickling filter investigation of petroleum wastes, Baker and Weston (32) studied the effects of alkyl benzene sulfonate on purification. With syndet loadings up to 348 mg. per liter there was 23 per cent removal. Thus, it began to appear that the alkyl benzene sulfonates were the basis of the syndet problem. House and Fries (33) set up experiments in a small activated sludge package plant with a radioactive labeled syndet. The sulfur atom on the sulfonate group was tagged. The sulfonate group was oxidized over to sulfate, indicating removal from the molecule, from 80 to 90 per cent of the syndet. During this same time the treatment plant was only operating at 70 to 75 per cent B.O.D. removal efficiency. Laboratory studies showed that the oxidation of alkyl benzene sulfonate was a factor of the dissolved oxygen content and that the fraction of syndet removed by biological treatment was unaffected by syndet concentrations up to 25 mg. per liter of active alkyl benzene sulfonate.

## Water Treatment

Although the basic syndet problem revolved around the biological stabilization of the syndet in sewage treatment plants, water treatment plant operators were faced with certain misgivings as to the effect the syndets might have on the various water treatment processes. Cross *et al.* (34) examined the effects of six different commercial syndets upon the coagulation of Lake Michigan water and found that there was usually an interference to coagulation above 5.0 mg. per liter of syndet. One of the blessings of water treatment is that sewage and sewage effluent are diluted to a considerable extent with natural runoff water before being treated.

### *Frothing*

Needless to say, a situation developed where it appeared that syndets were responsible for froth on the coagulation basin of the Osawatomie, Kans., water softening plant (35). Upstream at Ottawa, Kans., the water treatment plant was not troubled, even though the water was taken from the same stream. The only difference was that Osawatomie took in water from the same stream after it received the treated sewage from Ottawa.

Operating personnel first noticed trouble after the introduction of syndets in Ottawa. Retail sales indicated the Ottawa sewage could have a syndet concentration of 53 mg. per liter. A frothing effluent from the Ottawa sewage plant was considered evidence of the existence of a large concentration of syndet. Laboratory studies indicated that syndet concentrations from 3.0 to 3.5 mg. per liter could interfere with treatment at Osawatomie. Analyses of the syndet concentration in Ottawa raw sewage showed 44 mg. per liter. The activated sludge treatment plant reduced it to 39 mg. per liter. Dilution in river water dropped the concentration to 6.6 mg. per liter while flow downstream for 28 miles dropped the syndet concentration to 3.0 mg. per liter. Thus, it appeared that syndets could have been the problem.

Wheeling, W. Va. (36) was faced with a frothing river to draw upon for water supply in December, 1953. Analyses of the froth indicated the presence of syndet. Thus, it was not

surprising that syndets received the blame when there was difficulty in flocculation.

Vaughn *et al.* (37)(38) summed up the syndet problem in water treatment as froth on the settling basin, tastes and odors, problems with coagulation and sedimentation, lower iron removal, frothing of the finished water, and possible deterioration of the water in the distribution system. They conducted extensive tests to overcome the syndet effects. Activated carbon removed syndets in accordance with the Freundlich adsorption equation:

$$\frac{\text{Syndet adsorbed}}{\text{Activated carbon added}} = K\ (\text{Syndet remaining})^{1/n}$$

Unfortunately, considerable activated carbon was required to adsorb the syndet.

Alum had little effect on removing syndet, whereas ferric chloride had only slightly better efficiency. Bentonite clay could also adsorb the syndet, but only at a very low efficiency. Primary rosin amine acetate was extremely effective in removing the syndet. Primary rosin amine acetate is a cationic material that will precipitate any anionic syndets; but it is a strong skin irritant and cannot be used.

*Coagulation and Filtration*

Sanford and Gates (39) examined the effect of 20 mg. per liter of alkyl benzene sulfonate on the filterability of coagulated and settled water. Although the syndet did not have any effect on the bacteria and on aluminum removal, concentrations of syndet greater than 5 mg. per liter caused more rapid loss of head through the sand filter.

Investigating the coagulation problem, Smith *et al.* (40) found that the effects of syndets could be overcome by adding more coagulant, alum in this case. The additional coagulant demand was created by the action of the complex phosphates in the syndets.

Howells and Sawyer (41) confirmed this conclusion using color removal as the criteria of good coagulation and sedimentation rather than turbidity reduction as used by Smith *et al.* The coagulation problem increased linearly with the phosphate concentration in the water. The phosphate ties up the $Al^{+++}$ ions and prevents normal reaction until an excess of $Al^{+++}$ ions are present. The surface active fraction of the syndets was not found to have any effect on coagulation.

## Discussion

Considerable evidence has been presented in the literature implicating syndets as the cause of many of the problems which have arisen in sewage and water treatment plants since World War II. Much of the evidence implicating syndets has been indirect, rather than direct, as a result of the lack of an adequate analytical technique for measuring syndets. For this reason, it has been impossible to ascertain the exact role of syndets in the operational problems.

*Biological Degradation*

The basic problem with syndets stems from the degree of biological degradation of the syndets in sewage treatment plants or in natural receiving bodies of water. It has been shown that the biological degradation of syndets, as well as any organic compound, is dependent on its chemical structure. If syndets are to cause trouble, the blame must reside with those syndets which are produced and used the most. The anionic syndets are the major group of syndets in use today, and the alkyl sulfates and alkyl benzene sulfonates are the major types of anionic syndets.

Laboratory studies have shown that the alkyl sulfates can be metabolized quite readily, but the alkyl benzene sulfonates are resistant to biological metabolism by the microorganisms normally contained in sewage. It is in the resistance to metabolism by the alkyl benzene sulfonates that syndets

might be implicated in sewage treatment plant operational problems. Why the alkyl benzene sulfonates are resistant to biological metabolism is a question which has not been answered but which must be answered before a complete understanding of the problem can be obtained.

*Sewage Treatment Problems*

Present syndet production indicates that current sewages should contain an average of 10 mg. per liter of surface active agent and future predictions indicate an average of 14 mg. per liter of surface active agent by the end of the next six years. All of this material is not resistant to biological metabolism. At the present time only 5 mg. per liter of alkyl benzene sulfonate should be the average concentration of biological resistant syndets. Little research has been done on the effect of this low concentration of alkyl benzene sulfonate on sewage treatment systems. It definitely appears that this average syndet concentration is well below the toxic threshold of the various groups of microorganisms making up the biological treatment systems.

Most of the syndet problems in activated sludge systems appear to be related to frothing. There is little doubt that the occurrence of frothing since World War II can be related in part to increased usage of syndets. But are syndets the sole cause of froth? It has been pointed out that froth occurred in activated sludge systems long before syndets came into use. Such frothing was not widespread and was quickly dispersed by raising the mixed liquor suspended solids concentration. This type of frothing appeared to be related to the biochemical nature of the system. It may well be that frothing is related to syndets in conjunction with other compounds, such as proteins, which tend to stabilize the froth. The combination of unreacted, biologically stable syndet with protein decomposition products of the microorganisms are the real cause of froth persistence. This is another question which must be answered before the syndet problem has been resolved.

Increased oxygen requirements in activated sludge have been attributed to syndets. If this is so, the increased oxygen requirements must be related to the rate of oxygen transfer from the bubble to the liquid, because the rate of biological metabolism of the predominate syndet is very low. It has been shown that syndets reduce the rate of oxygen transfer in tap water; also it has been shown that many types of organic compounds reduce the rate of oxygen transfer in tap water. The question which remains to be settled is the effect of syndets on the oxygen transfer in sewage. It may well be that the other types of organic matter will overshadow the effect of the syndets in the problem of oxygen transfer. This point needs further research.

Reduced efficiencies of primary treatment devices have been forecast for syndet-containing sewages. There is little information of a concrete nature to back this statement. There is some evidence that the decrease in soaps through replacement by syndets has reduced the total quantity of organic matter removed in the primary tank. Because the use of syndets for soaps replaced an easily metabolized compound for a slowly metabolized compound, the organic strength of the sewage decreased quite rapidly. With less organic matter being removed from sewage containing less organic matter, the efficiency of treatment expressed as per cent decreased in some instances. The change in efficiency of primary treatment units since the introduction of syndets does not, however, appear to be of sufficient magnitude to be a problem.

In a few instances, holding grease in suspension resulted in transferring more of the organic load to the secondary treatment device. In some systems, this additional organic load was enough to cause problems. Ordinarily, the concentration of additional organic

matter carried over into the secondary treatment devices by syndets is not sufficient to warrant further consideration of this aspect of the problem. The concentrations of syndets now in sewage do not have an adverse effect on the stabilization of the other organic compounds in activated sludge systems and will not pose a toxicity problem.

Lower gas yields in digesters were attributed to syndets. This has been caused by a reduction in the total quantity of organic matter being removed in the primary device and sent to the digester. The gas yield per pound of organic matter destroyed is the same with and without syndets. The rate of decomposition of organic matter in digesters has not been reduced by syndets nor has any digester operation been affected by syndets.

Thus, the syndet problem in sewage reduces itself to frothing. Whether frothing is due to syndets or not does not bother the operator, he must control that froth. Three schemes have been devised for froth control: (a) increased mixed liquor suspended solids concentrations, (b) antifroth chemicals, and (c) sprays.

Increasing suspended solids in the mixed liquor has proven to be an effective control in plants where this can be done. In plants where this is not possible or desirable, antifroth chemicals have been used with good results. The best liked method and probably the most consistently efficient is the spray method for beating down the froth on the surface. It may well be that spray control of frothing will become a standard feature in the design of activated sludge systems in the near future.

*Water Treatment Problems*

The sewage treatment plant problems related to syndets were more apparent than those of the water treatment plant and have received more attention. For the most part, the surface active fraction of syndets has not been shown to be detrimental to water treatment plant operations as currently practiced. However, the syndet builders have been implicated as the syndet problem in water.

The phosphate builders exert a coagulant demand which must be satisfied if good floc is to be formed. For this reason there may be a tendency for coagulant dosages to increase in plants taking water receiving sewage at some point above the intake. The phosphates may increase the algae problem and its resultant tastes and odors in some streams. This may be the biggest problem for future water treatment plant operators as far as syndets are concerned.

Most of the syndet problems in water treatment plants have arisen after drought periods when the dilution factor was low. Normally, the dilution of the syndet-containing sewage or sewage treatment effluent is sufficient to prevent any major problems. But there will be some abnormal conditions which will stimulate problems related to the persistence of syndets in the receiving water.

Syndets have caused a basic change in the chemical nature of sewage, the first basic change since the advent of modern sewage treatment devices. Syndets have upset the "status quo" and in so doing have pointed up the major weakness of sanitary engineering, the lack of understanding of the basic concepts of waste disposal in relation to the solution of practical problems. In replacing soaps with the syndets, sewage has become weaker in B.O.D. and lower in suspended solids.

These two changes are sufficient to warrant a complete reexamination of sewage treatment plant design. The engineer must decide in view of the changes in sewage whether or not the current treatment units are the best or whether they should be changed completely. This is a challenge that stems from modern technology and it is a challenge that must be met rather than avoided.

*Solution of Syndet Problems*

There appear to be two schools of thought on the solution of the syndet problem. One solution appears to be to change the chemical structure of the syndet so that it can be biologically degraded; the other appears to be to change the treatment design to compensate for the action of syndets. As far as the sanitary engineer is concerned changing the chemical structure of the syndet would be the best solution. But this would not be an easy task.

The syndet manufacturers have put many years of effort and have been put to much expense in developing the alkyl benzene sulfonate type of syndet. The alkyl benzene sulfonate is a cheap and an extremely effective syndet. For these reasons, industry has been attracted to it. But like all products, there are efforts being made to find better materials for syndets. One of the most promising ideas is the building of the syndet from a sugar base.

*Research*

It will be some time before a change will be made in syndet structure and the engineer must solve the problems at hand today. In an effort to aid in the solution of the syndet problem, the Association of American Soap and Glycerine Producers has sponsored four major research projects in four universities, as follows:

1. Massachusetts Institute of Technology: Study of the breakdown of commercial alkyl benzene sulfonate by pure culture bacteria.
2. University of California: Study of the fate of commercial alkyl benzene sulfonates in sewage treatment systems.
3. University of Wisconsin: Study of foaming by commercial alkyl benzene sulfonates.
4. University of Illinois: Study of the effect of complex phosphates used as builders in syndets on natural receiving waters.

These projects are being carried out in addition to the research being carried on by each individual company affiliated with the American Soap and Glycerine Producers. The main project of the member companies is the development of an absolute measure of alkyl benzene sulfonates in water and sewage. Other projects are being sponsored by the U. S. Public Health Service through grants from the National Institutes of Health and projects at the Robert A. Taft Sanitary Engineering Center. This mass of research is rapidly pointing to the cause and the control of the syndet problem. But all of the answers will not be determined tomorrow, next month, or even next year. It will be many years before all of the questions on syndets can be answered.

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# THE VALLEY SETTLING BASIN FACILITIES, LOS ANGELES, CALIFORNIA *

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Like most California cities, Los Angeles has experienced a tremendous post-war population increase. Consequently, its sewage treatment and collection facilities required extensive enlargement.

The Los Angeles Hyperion sewage treatment plant, placed in operation in 1950, has operated satisfactorily since that date and will be enlarged under current designs to treat sewage from the Los Angeles area for many more years.

However, the Los Angeles sewage collection system has had difficulty in keeping up with the increasing load. By the latter part of 1953, the sewage flow from the San Fernando Valley, Burbank, and Glendale had increased so greatly that peak sewage flow rates caused overflows from critical manholes on the Glendale Outfall Sewer, a portion of the main sewer system, tributary to the Hyperion treatment plant. A serious health hazard resulted.

To reduce the hazards from these overflows the Sewer Maintenance Division of Los Angeles constructed a bypass facility and placed a portable chlorination unit at the site so that during periods of peak flow, chlorinated sewage could be by-passed from the outfall to the Los Angeles River upstream from the most critical sections of the outfall. At the same time, design was undertaken on a temporary chemical treatment plant to provide a greater degree of treatment for the sewage diverted from the main outfall to the river. The permanent solution to the problem of inadequate sewer capacity will be the construction and use of the San Fernando Valley Relief Sewer and the North-Central Outfall Sewer, which will convey the sewage from the San Fernando Valley directly to the Hyperion plant. The San Fernando Valley Relief Sewer was placed in operation in April, 1956, and the North-Central Outfall is scheduled to be completed in 1958.

The chemical treatment plant designed to provide the most satisfactory temporary solution to this problem is called the Valley Settling Basin, and was placed in operation in August, 1954. Its function is to divert from the main outfall system peak flows in excess of the hydraulic capacity of the outfall, chemically precipitate and chlorinate the sewage, and discharge the treated effluent to the Los Angeles River.

## Plant Description

The Valley Settling Basin plant is located upstream from the most critical sections of the main outfall system, adjacent to the Los Angeles River at the southeastern extremity of the San Fernando Valley. The plant is physically separated into two parts: the headworks which is located on the north side of the river in the City of Burbank, and the main plant on the south side of the river. The two sections are connected by a 7,000-ft. concrete influent line of 36- and 42-in. pipe. The remoteness of the headworks from the main plant was dictated by the necessity of intercepting

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the outfall sewer upstream from all critical sections and constructing the main plant in the City of Los Angeles on land owned by the City.

The headworks section was constructed above the 48-in. semi-elliptical outfall sewer and a section of the outfall from the spring line up was removed. To divert the sewage, two channels were constructed at right angles to the outfall. These channels join and flow into the plant influent line. Each channel is equipped with an automatic bar screen, and the influent line has a sluice gate which can be remotely operated from the main plant. In addition, a manually operated gate has been installed on the main outfall to restrict the flow and allow greater diversion through the headworks. Screenings from the bar screens are returned to the outfall sewer.

The main plant consists of a chemical handling building, a Parshall flume room, a pump room, an influent building, a primary settling tank, an effluent building, a chlorination and chlorine storage room, and an office and laboratory. There are no solids-handling units as the sludge and scum are returned continuously to the outfall sewer.

The chemical handling building contains two 500-gal. and two 800-gal. chemical mixing tanks, and an automatic proportioning chemical feeder. Aluminum sulfate is used for flocculation and is delivered by truck in granular form packaged in 100-lb. bags. The chemical is mixed as a water solution in the two 800-gal. tanks and automatically fed to the sewage.

The flume room contains a 30-in. Parshall connected to a pneumatic flow transmitter which controls the chemical feeder in proportion to the sewage flow and also transmits to a recording and integrating receiver. A flash mixer is installed immediately downstream from the flume where the flocculating chemicals are added.

There are two parallel settling tanks, each 17.5 ft. wide, 10 ft. deep, and 300 ft. long, equipped with longitudinal collectors. The tanks have a volume of 786,000 gal. and a detention period of 1 hr. at the peak design flow rate of 30 c.f.s. The tanks were designed to perform three functions. The first 100 ft. of each tank contains 9 flocculating paddles for building up the floc size. There is no separation between the flocculating and the settling portions of the tank. Accordingly, the operation of the flocculating paddles caused excessive turbulence in the effluent end and resulted in the discharge of floc over the effluent weirs. Therefore, the flocculators have not been used. The tank inlets consist of a series of 6-in. wide slots from which the sewage impinges against a target baffle. This action together with the flash-mixing chamber results in the formation of an excellent floc without using the tank flocculators.

The second 100-ft. section of the tank provides for sludge settling and chlorine is added at the end of the section through submerged diffusers. The final 100 ft. of tank length was provided for the chlorine contact time, after which the effluent flows over V-notched weirs, then to a 36-in. sewer to the Los Angeles River. Provision was made for prechlorination and postchlorination. A 6,000-lb. per day chlorinator was installed, together with necessary appurtenances and facilities for handling ton-chlorine containers.

The current plant staff consists of 14 men, including a chief operator, chemist, and mechanic, and is administered by the Sewage Treatment Division of the Bureau of Sanitation. The total cost of the plant exceeded $500,000.

### Hydraulic Control

The critical portion of the Glendale Outfall Sewer to be protected is approximately 10 miles long and the manhole from which overflows first

occur is about eight miles downstream from the plant. The cities of Burbank and Glendale, and part of Los Angeles, contribute sewage to the outfall between the plant headworks structure and the control manhole. The eight-mile distance between the point of diversion and the point of overflow results in a delay of 45 min., corresponding to the wave-travel time, before the effect of adjustments at the headworks is apparent at the control manhole. The full effect of any adjustment is delayed for approximately 2 hr. Accordingly the factor of anticipation is a very important one in operation of the plant. Therefore, an unusual hydraulic control system is used.

The plant office is the nerve center for control of the system and the operator in charge is stationed there. Instrumentation provides for receiving and recording the sewage level at the control manhole, the flow in the main outfall downstream from the headworks building, and the flow diverted to the plant. Push button controls provide remote operation of the headworks gate, the bar screens, and the chemical feed system.

As the existing sewer system has sufficient hydraulic capacity for the periods of low flow, diversion to the plant is not continuous. In August, 1954, when the plant was first operated, diversion took place for 4 to 6 hr. on Mondays only. As the sewage flow tributary to the system increased, diversion was required daily for periods up to 16 hr. During the daily low flow period, the settling tank is dewatered to the outfall sewer, thus reducing the discharge to the river.

Details of the methods employed for determining the minimum flows to the plant which will adequately protect the outfall are extremely complicated, and only a few of the criteria will be summarized here.

At the control manhole, the outfall is a 42-in. semi-elliptical sewer section. The distance from the soffit of the outfall to the street surface is 7 ft. With the sewage level at the street surface, the outfall has a capacity in the order of 90 c.f.s. Operating results have shown that a flow change of about 2.6 c.f.s. corresponds to a sewage level change of 1 ft.

It has been determined that a freeboard of from 1 to 2 ft. below the street at the control manhole will allow the plant to be operated satisfactorily and will provide an adequate safety factor against overflow of the outfall. At the same time the minimum quantity of sewage is diverted from the outfall.

This 1- to 2-ft. freeboard criterion means that an unanticipated flow of from 2.6 to 5.2 c.f.s. (or about 3 to 6 per cent of the outfall capacity) would cause sewage to overflow to the street, and, because of the lag time involved, the overflow would continue for 45 min. to 2 hr. before adjustments at the plant could eliminate the overflow.

It is the responsibility of the operator in charge to consider such factors as the day of the week, the time of day, the existing level and rate of change at the control manhole, and the weather conditions before determining whether to divert more or less sewage to the plant. Weather conditions affect the flow, not because of storm-water infiltration but because sunny weather results in increased laundry flow from the residential areas. In fact, the most trying experiences in flow control have occurred when Monday and Tuesday have been rainy or overcast, and Wednesday is bright and sunny. Such a combination of circumstances will increase the peak sewage flow rate from the San Fernando Valley by from 30 to 40 per cent.

All things considered, it behooves the successful operator of this plant to be part hydrologist, part meteorologist, an expert prophet, and to possess a relatively thick skin when he has misjudged some factor.

## Plant Performance

The Valley Settling Basin plant has had considerable variation in its treatment methods. Table I summarizes the basic data for design and actual operating conditions.

Ferric sulfate was the chemical coagulant originally intended to be used. However, several disadvantages soon became apparent. The material, as delivered, contained about 10 per cent or more insolubles which caused stoppages in the mixing tank outlet piping and the chemical feeder. The dosage required for satisfactory clarification was about 400 p.p.m. on an anhydrous basis. At this dosage level, the effluent had a pH of less than 3 and left a bright orange stain on the settling tank concrete surfaces and on the concrete river channel. To raise the pH to 6, 150 p.p.m. of lime was required, and this produced a cloudy effluent.

After experimentation it was found that aluminum sulfate would be more satisfactory. This material produced excellent clarification with a dosage rate of 350 p.p.m. and resulted in an effluent pH of 6.5 without the addition of lime. No insoluble material was present to cause clogging difficulties. In addition, an 800-gal. batch containing 5 lb. of alum per gallon of water could be dissolved in approximately 30 min., as compared with 2 hr. for ferric sulfate.

For several months treatment results were excellent. Then as increased flow rates were required to be diverted to the plant, it was noted that at a flow somewhat greater than 20 c.f.s., floc was discharged over the effluent weirs. The quantity of floc discharged increased rapidly as the flow rate rose to 25 and 30 c.f.s., becoming as great as 15 to 20 ml. per liter of settleable solids. Change in the alum dosage had no effect upon this condition.

The floc discharged first appeared at the weir located at the effluent wall of the tank and the condition then progressed upstream to the other weirs. Assuming that a flow path existed along the tank floor against the effluent wall and then countercurrent at the tank surface, the appearance of the floc in the manner described indicated that it had settled, been carried along the tank floor, and then picked up by

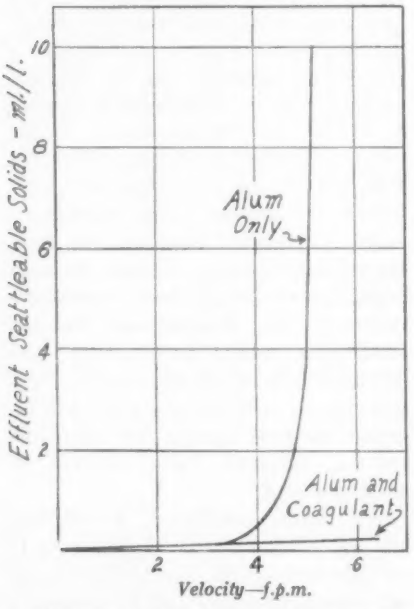


**FIGURE 1.—Suspended solids removals with alum, and alum and synthetic coagulant.**

**TABLE I.—Basic Design and Operating Data**

| Item | Design | Operation |
|---|---|---|
| Peak flow rate (c.f.s.) | 30 | 45 |
| Detention at maximum flow (hr.) | 1 | 0.67 |
| Suspended solids (p.p.m.) | 430 | 516 |
| Removal (%) | 80–90 | 90 |
| B.O.D. (p.p.m.) | 250 | 435 |
| Removal (%) | 75–80 | 65 |
| Chemical dosage (p.p.m.): | | |
| Ferric Sulfate | 200 | 400 |
| Aluminum Sulfate | — | 350 |
| Synthetic coagulant* | — | 2 |
| Prechlorination | 5 | 0 |
| Postchlorination | 25 | 18 |

* Separan.

**TABLE II.—Operating Data for the Valley Settling Basin, Los Angeles, Calif., for the Fiscal Year 1954–55 and the Period July 1, 1955 to Dec. 31, 1955**

| Item | Fiscal Year 1954–55 | Six months July-Dec., 1955 |
|---|---|---|
| Flow (m.g.d.) | 3.5 | 7.2 |
| Suspended solids: | | |
| Influent (p.p.m.) | 595 | 516 |
| Effluent (p.p.m.) | 42 | 49 |
| Removal (%) | 92.7 | 90.5 |
| B.O.D.: | | |
| Influent (p.p.m.) | 334 | 435 |
| Effluent (p.p.m.) | 121 | 155 |
| Removal (%) | 63.8 | 64.3 |
| Chemicals used: | | |
| Aluminum sulfate (lb./mil. gal.) | 2,940 | 2,810 |
| Chlorine (lb./mil. gal.) | 139 | 147 |

**TABLE III.—Operating Costs for the Valley Settling Basin, Los Angeles, Calif., for the Fiscal Year 1954–55 and the Period July 1, 1955 to Dec. 31, 1955**

| Item | Fiscal Year 1954–55 | | Six Months July–Dec., 1955 | |
|---|---|---|---|---|
| | Total ($) | Per Mil. Gal. ($) | Total ($) | Per Mil. Gal. ($) |
| Salaries | 42,947 | 37 | 29,943 | 22 |
| Chemicals | 81,997 | 70 | 94,187 | 71 |
| Miscellaneous | 6,491 | 6 | 2,750 | 2 |
| Total | 131,435 | 113 | 126,880 | 95 |

the currents existing at the effluent end of the tank.

Although most authorities indicate that the pick-up of settleable solids is not a problem until velocities reach 10 f.p.m., the critical value for alum floc appears to be much lower. A similar test of the Hyperion primary settling tanks has shown the critical velocity to be about 6 f.p.m. for primary sludge.

The problem of controlling the alum floc discharge reached major proportions as the flow diverted to the plant continued to increase. After considerable laboratory experimentation to produce a more dense floc, a plant-scale test was made using 3 p.p.m. of a synthetic coagulant.*

The plant-scale tests confirmed the laboratory results, and facilities were added for mixing and dosing the synthetic coagulant. The practice of adding 2 to 3 p.p.m. of this coagulant whenever the flow rate exceeds 20 c.f.s. has successfully eliminated the discharge of any floc in the plant effluent. The plant-scale results, using alum alone, and the synthetic coagulant and alum are shown in Figure 1.

Laboratory tests and plant-scale experiments have also been performed using the synthetic coagulant and Bentonite clay in lieu of aluminum sulfate. These tests have shown considerable promise and could result in a substantial saving in chemical treatment costs. There is, however, some reduction in B.O.D. and suspended solids removal as compared with the use of alum and the synthetic coagulant. In addition, the effluent lacks the almost sparkling clarity which results from the use of alum and the synthetic coagulant. In view of the high degree of treatment desired for the sewage discharged to the Los Angeles River, it was felt that no reduction in the effluent quality could be permitted and the use of aluminum sulfate and synthetic coagulant has been continued.

Treatment results for the fiscal year 1954–55, and the period June to December, 1955, are given in Table II. The cost of operation during this same period is given in Table III.

* Separan No. 2610, Dow Chemical Co.; synthetic polymer of acrylic acid.

# Industrial Wastes

## CURRENT PRACTICES IN MUNICIPAL TREATMENT OF INDUSTRIAL WASTES *

SUBCOMMITTEE ON COMBINED TREATMENT OF MUNICIPAL AND INDUSTRIAL WASTES OF THE CHEMICAL INDUSTRY ADVISORY COMMITTEE OF THE OHIO RIVER VALLEY WATER SANITATION COMMISSION

*Cincinnati, Ohio*

### FOREWORD AND ACKNOWLEDGMENT

Control of industrial waste discharges to prevent the impairment of water resources is one of the major tasks with which the Ohio River Valley Water Sanitation Commission is concerned. In this effort the eight-state agency—representing Illinois, Indiana, Ohio, Pennsylvania, New York, Virginia, West Virginia and Kentucky—has invited the participation of advisory committees representing generic industry groups. One of these, the Chemical Industry Committee, recently addressed itself to a survey of practice and experience relating to combined treatment of industrial waste in municipal sewage treatment plants.

Results of the survey with conclusions were submitted to the Commission to aid in its deliberations and for use among its member states, industries, and municipalities in the Ohio River Valley. The Commission has consented to release of this report with the understanding, however, that approval for publication is not to be construed necessarily as Commission endorsement of any views expressed.

The Commission wishes to acknowledge with appreciation the efforts of the Chemical Industry Committee, under the chairmanship of Richard Rhodes, assistant to the president, Koppers Company, in developing the report. In particular, the Commission recognizes the work of the subcommittee consisting of Chairman Virgil E. Gex, Procter and Gamble Company; Chester H. Allen, Hilton-Davis Chemical Company; Don E. Bloodgood, representing the Commercial Solvents Corporation; J. F. Byrd, Procter and Gamble Company; and James Crane, Toms River, Cincinnati Chemical Company.

EDWARD J. CLEARY
*Executive Director and*
*Chief Engineer, ORSANCO*

More and more attention is currently being focused on the problem of combined or separate treatment of municipal and industrial wastes, as increasing numbers of communities are being required to install waste treatment facilities, and are being forced to answer the question, "Shall we combine treatment of municipal and industrial wastes in one municipal facility, or shall industry provide its own treatment facilities for its own specific and often highly unpredictable wastes?" This question can be more logically answered if information is available as to what other communities have done in combined treatment, what difficulties they may have had, how they have met these difficulties, and what effects the difficulties may have had on treatment plant performance.

To attempt to draw up-to-date in-

* Submitted to the Ohio River Valley Water Sanitation Commission, January 24, 1957.

formation together on these questions, a survey questionnaire was sent to nearly 200 sewage treatment plants handling combined municipal and industrial wastes, distributed throughout the United States. One hundred replies to the survey were analyzed, and the data contained were grouped to obtain answers to the questions asked.

In general, it can be said that (a) a great deal of industrial waste is treated in municipal treatment plants; (b) both municipalities and industry approach the problem with a spirit of cooperation and mutual confidence; (c) a great many operating problems arise from the presence of the industrial wastes but most of these problems are solvable within the treatment plant; (d) certain solids and materials toxic to bacterial activity cannot be properly handled in a municipal treatment plant and should be kept out of it; and (e) the operating problems produced by industrial wastes do not, for the most part, seem to reduce seriously the treatment efficiencies of the municipal plants.

## Objectives of Survey

The broad objective of the survey was to determine what the current practices and experiences are in treatment of combined municipal and industrial wastes in municipal sewage treatment plants in the United States. To obtain this information, the questionnaire included questions aimed at several specific targets.

It was desired to find the source and extent of the industrial waste load handled by municipal plants. Plant operators were asked to indicate what types of industry contributed wastes to their plants, and whether each industry's contribution was a large, medium, or small portion of their treatment plant load. They were also asked to estimate the percentage of total flow, B.O.D., and suspended solids attributable to industrial wastes.

An important objective was to find the effect of industrial wastes on treatment plant operation. Operators were asked to indicate whether industrial wastes caused any continuing or frequently recurring operating problems in their treatment plants. If such problems occurred, they were asked to describe the problem, the particular material causing it if known, and to indicate in what section of the treatment plant the trouble occurred.

The effect of industrial wastes on treatment plant performance is an important consideration in treatment of combined wastes. Each plant was asked to furnish data on influent and effluent concentrations of B.O.D. and suspended solids. By comparing the concentrations of those plants without industrial waste problems with those of plants experiencing various types of difficulties, some conclusions might be reached as to the effects of industrial wastes on sewage strengths and their effects on treatment plant performances.

Some measure was desired of the seriousness of any treatment plant operating problems caused by industrial wastes. To obtain this measure, operators were asked to indicate which of four categories was representative of the industrial waste problem at their plant.

1. Can be solved by installing adequate equipment, at an added capital cost.
2. Can be solved by using proper or special operating procedures, at an added operating cost.
3. Can be tolerated at a reduced plant efficiency or operating inconvenience.
4. Cannot be solved at treatment plant.

The attitude of municipalities now treating industrial wastes was of interest. Each treatment plant operator was asked if any industrial wastes were excluded from the system, and, if so,

what general basis was used for deciding what wastes were inadmissible.

## Scope of Survey

The survey was directed to municipal sewage treatment plants in the United States which treated industrial wastes combined with general municipal wastes. The official responsible for pollution control activities in each of the 48 states was requested to furnish a list of sewage treatment plants within his state that handled combined municipal and industrial wastes. From the lists received, all municipalities under 10,000 population were eliminated to keep the survey to a manageable size, and the survey questionnaire was mailed to the remainder.

One exception to this procedure was the State of Missouri, where the Department of Public Health Engineering requested that survey forms be mailed to them, in order that they might aid plant personnel in filling out the questionnaire. Returns from Missouri, therefore, included some cities with populations less than 10,000.

The survey sample is thus not random with respect to sewage treatment plants because it was restricted to those treating combined wastes. It is probably not completely random with respect to these, since the state pollution control officials undoubtedly suggested those plants whose wastes they knew contained significant quantities of industrial wastes. Nor are any of the data weighted in proportion to plant flows; in all tabulations of results, a small treatment plant carries as much weight as a large one.

The survey sample included all geographic areas of the United States. Questionnaires were sent to a total of 192 treatment plants in 37 of the 48 states, and replies were received from 100 plants in 28 states.

## Analysis of Data

Analysis of the data has been made along the general lines given as the objectives of the survey. All treatment plants were divided into two general types: (a) primary, where plain sedimentation was the principal treatment given the main sewage flow, and (b) secondary, where biological treatment either by activated sludge or trickling filters was also given to the main sewage flow.

A synopsis of the survey returns from all treatment plants is as follows:

1. One-hundred survey forms were returned.
2. Thirty-seven plants employed primary treatment; 63 employed primary and secondary treatment.
3. One-hundred per cent of the answering plants handled industrial wastes.
4. Thirty-nine per cent of the plants reported no trouble in handling industrial wastes.
5. Sixty-one per cent of the plants reported varying degrees of difficulty in handling industrial wastes.

The degree of severity of the problems experienced is indicated by the following tabulation:

| Type of Problem | Per Cent of Plants* |
|---|---|
| Have no problem. | 39 |
| Can be tolerated at reduced efficiency. | 20 |
| Can be handled with special operating procedures. | 14 |
| Can be handled by installing proper equipment. | 29 |
| Cannot be handled at treatment plant. | 17 |

* Percentages total to more than 100 per cent because some plants indicated more than one possible solution to a problem.

Plants were asked to estimate the percentages of their flow, B.O.D., and suspended solids which came from industrial wastes. As might be expected, replies covered a broad range, from 5 to 85 per cent. For the median treatment plant, industrial wastes contributed 25.5 per cent of the flow, 36.25 per cent of the B.O.D., and 32.5 per cent of the suspended solids. These median values are substantial, but of

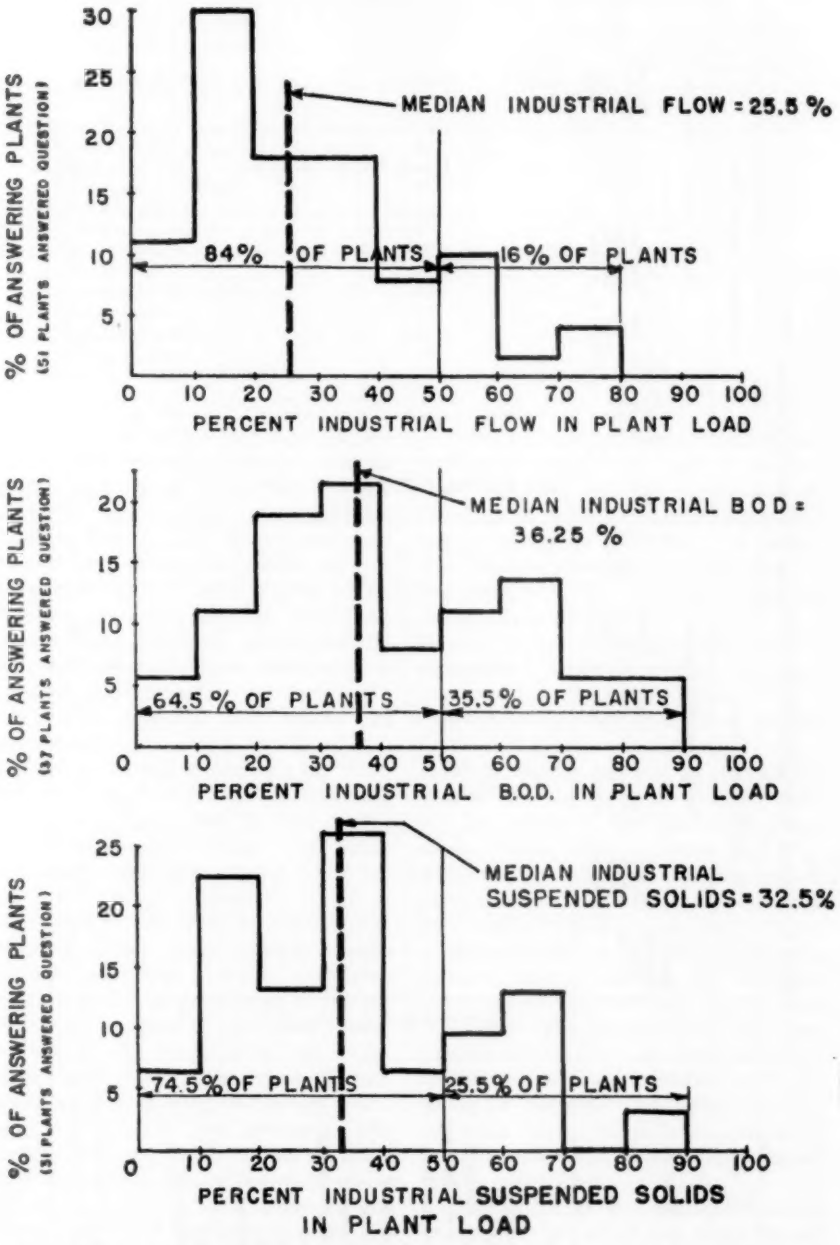
% OF ANSWERING PLANTS
(51 PLANTS ANSWERED QUESTION)
MEDIAN INDUSTRIAL FLOW = 25.5 %
84% OF PLANTS
16% OF PLANTS
PERCENT INDUSTRIAL FLOW IN PLANT LOAD
% OF ANSWERING PLANTS
(57 PLANTS ANSWERED QUESTION)
MEDIAN INDUSTRIAL B.O.D. = 36.25 %
64.5 % OF PLANTS
35.5% OF PLANTS
PERCENT INDUSTRIAL B.O.D. IN PLANT LOAD
% OF ANSWERING PLANTS
(51 PLANTS ANSWERED QUESTION)
MEDIAN INDUSTRIAL SUSPENDED SOLIDS = 32.5%
74.5% OF PLANTS
25.5% OF PLANTS
PERCENT INDUSTRIAL SUSPENDED SOLIDS IN PLANT LOAD

FIGURE 1.—Graphic analyses of the data on municipal treatment of industrial wastes.

TABLE I.—Sources of Industrial Wastes and Extent of Effects on Treatment Plants

| Industry | Primary Treatment Plants | | | | | | | Secondary Treatment Plants | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | Have Industrial Waste Trouble | Possible Corrective Measures | | | | | No. | Have Industrial Waste Trouble | Possible Corrective Measures | | | | |
| | | | Tolerate at Reduced Efficiency | Use Special Operating Procedures | Install Adequate Equipment | Cannot Solve at Treatment Plant | Did not Answer | | | Tolerate at Reduced Efficiency | Use Special Operating Procedures | Install Adequate Equipment | Cannot Solve at Treatment Plant | Did not Answer |
| Chemical | 12 | 2 | — | — | 1 | 1 | — | 10 | 1 | 1 | — | — | 1 | — |
| Steel | 9 | 2 | 1 | 1 | — | 1 | — | 3 | 1 | — | — | — | 1 | — |
| Metalworking | 14 | 3 | 1 | — | — | 2 | — | 16 | 2 | — | 1 | 1 | — | — |
| Metalfinishing | 16 | 3 | 2 | 1 | — | 1 | — | 17 | 2 | 2 | — | — | — | — |
| Petroleum refinery | 5 | 2 | — | — | — | — | 1 | 2 | — | — | — | — | — | — |
| Distillery and brewery | 13 | 1 | — | — | 1 | — | 1 | 11 | 1 | — | — | 1 | — | — |
| Coke and coal tar | 5 | — | — | — | — | — | — | 4 | 1 | 1 | — | — | — | — |
| Textiles | 10 | 1 | 1 | — | 1 | — | — | 14 | 6 | 1 | 1 | 5 | 1 | — |
| Pulp and paper | 9 | 5 | 3 | — | 2 | 1 | — | 4 | — | — | — | — | — | — |
| Packinghouse | 21 | 4 | 1 | — | 2 | 1 | — | 33 | 16 | 2 | 6 | 8 | — | — |
| Milk processing | 21 | 1 | — | — | 1 | — | — | 43 | 5 | 1 | — | 3 | 1 | — |
| Edible-oil processing | 4 | — | — | — | — | — | — | 6 | — | — | — | — | — | — |
| Canneries | 15 | 3 | 2 | — | — | 1 | — | 8 | 3 | — | 1 | 1 | 1 | — |
| Laundry | 29 | — | — | — | — | — | — | 40 | 2 | 1 | — | 1 | — | — |
| Tannery | 9 | 2 | — | 2 | 2 | — | — | 9 | 2 | — | 1 | 1 | — | — |
| Photographic | 7 | — | — | — | — | — | — | 7 | — | — | — | — | — | — |
| Other: | | | | | | | | | | | | | | |
| Poultry | 1 | 1 | — | — | — | 1 | — | 6 | 5 | 1 | — | — | 3 | — |
| Miscellaneous | 9 | 4 | 1 | 1 | 1 | — | 1 | 10 | 8 | 2 | 3 | 2 | — | 1 |
| Total | 209 | 34 | 12 | 5 | 11 | 9 | 3 | 243 | 55 | 12 | 13 | 23 | 8 | 1 |
| Per cent of troubles which can be solved as indicated | — | — | 35 | 15 | 32 | 26 | — | — | — | 22 | 24 | 42 | 15 | — |

TABLE II.—Location of Operating Difficulties Within the Treatment Plants

| Plant Section | Plants Equipped (No.) | Plants Reporting Troubles (No.) | Plants with Troubles Not Solvable at Treatment Plant | |
|---|---|---|---|---|
| | | | (No.) | (%) |
| Grit removal | 81 | 9 | 1 | 11 |
| Sedimentation | 100 | 29 | 1 | 3 |
| Chemical flocculation | 10 | 1 | 0 | 0 |
| Trickling filters | 45 | 14 | 4 | 29 |
| Activated sludge | 22 | 11 | 3 | 27 |
| Final settling | 12 | 10 | 0 | 0 |
| Disinfection | 46 | 4 | 0 | 0 |
| Raw sludge incineration | 2 | 0 | 0 | — |
| Sludge digestion | 92 | 34 | 8 | 24 |
| Sludge dewatering | 27 | 3 | 0 | 0 |
| Sludge drying | 68 | 4 | 0 | 0 |
| Digested sludge incineration | 6 | 0 | 0 | — |

equal interest is the fact that 16 per cent of the plants had 50 per cent or greater industrial waste flow, 35 per cent had 50 per cent or greater industrial B.O.D., and 25 per cent had 50 per cent or greater industrial suspended solids. In other words, a substantial number of the treatment plants were handling predominantly industrial wastes. These data are summarized in Figure 1.

Table I lists (a) the number of plants which reported handling each type of industrial waste, (b) the number who reported trouble in handling each type of waste, and (c) the possible corrective measures which might eliminate the trouble experienced. The latter might be considered an index of the severity of trouble experienced, ranging from trouble which can be tolerated through trouble requiring special operating procedures or the addition of equipment, to the type of problem which cannot be solved at the treatment plant. The over-all percentages of operating difficulties which can be solved by the measures indicated are shown at the bottom of Table I. Since some plants indicated more than one solution to a problem, the percentages add up to more than 100 per cent, but they represent a reasonable index to the over-all severity of operating problems arising from industrial wastes.

Table II indicates the sections of the treatment plant in which troubles were reported, and the percentage of troubles in each section which could not be solved at the treatment plant. The serious problems, not solvable at the plant, occurred primarily in sludge digesters, trickling filters, and activated sludge units, and were caused primarily by materials which inhibited bacterial activity, or by solids of various types which clogged filter nozzles or formed heavy scum layers.

Of particular interest in the survey results are the problems which could not be solved by the treatment plant alone. These were so varied that they defy any generalized description or tabulation; accordingly, a synopsis of each difficulty is given in Table III.

It is desirable to see what effects industrial wastes have on the ultimate performance of treatment plants, *i.e.* the actual removal of B.O.D. and suspended solids from the wastes before discharge to the receiving waters. Table IV presents these data averaged for each degree of difficulty reported by the treatment plants. Significant points noted are:

1. Both B.O.D. and suspended solids reductions, are about the same for all categories. There is no significant trend toward a decrease in efficiency of removal with increasing complexity of operating problems.

**TABLE III.—Operating Difficulties not Solvable at Treatment Plant**

| Treatment Plant | Offending Waste | Description of Difficulty |
|---|---|---|
| Fayetteville, Ark. | Feathers | Float in digester; clog spray nozzles of trickling filters. |
| Stockton, Calif. | Peach and apricot processing wastes | Wastes contain much nonsettling B.O.D. matter with high pH. Trickling filter has little effect in reducing B.O.D. Hence, during canning season, high B.O.D. wastes are discharged to river. |
| Los Angeles County, Calif. | Solvents and unidentifiable toxic compounds | Gas production depressed when toxic material received. |
| Orange County, Calif. | Citrus cannery wastes | Suspended solids from these wastes do not settle well, giving effluent with excessive suspended solids. |
| Southeast Works, San Francisco, Calif. | Tallow<br>Solvents and pigments | Plugs bar racks.<br>Concerned about possibility of explosive mixture. |
| Oxnard, Calif. | Cannery acid wastes | Lower pH and interfere with digestion. |
| Tampa, Fla. | Citrus press liquors | Inhibit digestion, forming heavy scum layers. |
| Dalton, Ga. | Lint<br><br>Feathers | Interferes with electrodes used in automatic controls. Clogs pump lines.<br><br>Stoppage of trickling filter nozzles; interfere with electrodes used in automatic controls. |
| Gary, Ind. | Metal pickle liquor | Clogs carborundum aeration tubes with iron oxide. |
| Wichita, Kans. | Chromium, copper, cyanide, cadmium | Destroy anaerobic digestion. |
| Macon, Mo. | Feathers, blood, grease | Clog trickling filter. |
| Trenton, N. J. | Dyes from pickling liquor | Discolor effluent. |
| Austin, Texas | Unknown | Inhibits anaerobic digestion. |
| Forth Worth, Texas | Chromium<br><br>Feathers | Inhibits gas production in digester.<br><br>Feathers form scum blanket in digester. |
| Harrisonburg, Va. | Feathers and grease | Feathers form scum blankets in digesters. Grease forms leathery membrane on sludge drying beds and inhibits sludge drying. |

2. Primary treatment plants with operating difficulties caused by industrial wastes appear to have higher B.O.D. and suspended solids loadings than do those plants without troubles. Thus, although the percentage removals are about the same, the primary plants with difficulties are discharging higher B.O.D. and suspended solids loadings to the streams because of their increased influent loadings.

3. For secondary treatment plants, no such clear-cut increase in load is noticeable for the plants experiencing

**TABLE IV.—Treatment Plant Performance Versus Operating Difficulties Due to Industrial Wastes**

| Type of Difficulty | B.O.D. | | | Suspended Solids | | |
|---|---|---|---|---|---|---|
| | Infl. (p.p.m.) | Effl. (p.p.m.) | Reduction (%) | Infl. (p.p.m.) | Effl. (p.p.m.) | Reduction (%) |
| (*a*) Primary Treatment Plants | | | | | | |
| None | 184 | 108 | 41 | 199 | 64 | 68 |
| Solvable by installing adequate equipment | 357 | 202 | 44 | 392 | 144 | 63 |
| Solvable by proper operating procedures | 243 | 121 | 50 | 418 | 124 | 70 |
| Can be tolerated at reduced efficiency | 252 | 161 | 36 | 308 | 121 | 61 |
| Cannot be solved by practical means at plant | 307 | 189 | 38 | 446 | 157 | 65 |
| (*b*) Secondary Treatment Plants | | | | | | |
| None | 305 | 28 | 91 | 297 | 26 | 91 |
| Solvable by installing adequate equipment | 365 | 45 | 88 | 445 | 36 | 92 |
| Solvable by proper operating procedures | 379 | 53 | 86 | 262 | 27 | 90 |
| Can be tolerated at reduced efficiency | 270 | 30 | 89 | 258 | 41 | 84 |
| Cannot be solved by practical means at plant | 298 | 33 | 89 | 342 | 21 | 94 |

operating difficulties; loadings, as well as removal efficiencies, are about the same for plants with difficulties as for those without.

Plant operators were asked if industrial wastes were excluded from their systems, and if so, what general basis was used to determine their exclusion. Respondents did not exclude industrial wastes as such. Forty per cent of the respondents maintained general prohibitions against explosive, toxic, or damaging materials, generally at the discretion of the city sanitary engineer. Only 11 per cent placed specified numerical limits on amounts or concentrations of specific materials acceptable to the municipal system. The remaining 49 per cent indicated no limitations on industrial wastes.

The analysis of the replies would not be complete without a comment on the general attitudes reflected. Implicit throughout all but a very few of the replies was a spirit of cooperation between industry and the municipality in the solving of a common problem. Where problems existed, both parties were trying to solve them, and if differences of opinion on the cause of a problem existed, a search for true facts, rather than an opinion-based argument, was the usual method for resolving the difference. These attitudes of a cooperative atmosphere cannot be reduced to tabulations and numerical analysis, but they constitute probably the most important factor in combined treatment of municipal and industrial wastes.

## Conclusions

Conclusions drawn from the survey can be based only on general trends, and there may be specific examples contradicting each conclusion. The

substantial majority of replies agree with the conclusions, indicating the general trends.

Although impossible of reduction to a table or number, there was implicit in the tone of the overwhelming majority of replies a spirit of cooperation between municipality and industry in solving the industrial waste treatment problem. This might be considered the most important conclusion of the survey. Most of the municipalities surveyed accepted industrial wastes either without reservation, or with only general prohibitions against materials harmful to the system or its function. Only 11 per cent of the respondents established fixed numerical limits on specific materials. Industry likewise was reported as generally willing to study and take care of real offenders. The two, municipality and industry, approached waste treatment as a common problem which they must both work to solve.

Most of the industrial waste treatment problems can be solved by increased operating effort or adequate equipment at the treatment plants. Sixty-one per cent of the plants reported operating troubles due to industrial wastes, but only 17 per cent indicated that these problems could not be solved within the treatment plant itself. However, the number of plants which cannot solve such problems within the treatment plant clearly indicates a responsibility by industry to keep certain wastes out of the municipal systems. In general, solid materials which clog even well-designed equipment, or materials toxic to bacterial activity, cannot be properly handled in municipal treatment plants.

The operating problems created by industrial wastes do not appear to affect appreciably the treatment plant performance in removal of B.O.D. and suspended solids. Plants which reported troubles from industrial wastes averaged essentially the same percentage reductions in B.O.D. and suspended solids as did those reporting no troubles. For primary plants, influent concentrations in the plants with troubles were somewhat higher than in the trouble-free plants, and effluent concentrations were correspondingly higher. No such differentiation was possible for secondary plants where concentrations and percentage reductions were essentially the same for both groups.

Major credit for this survey must be given to the sewage treatment plant operators for the conscientious effort which they devoted to answering the survey forms. The questionnaire represented only an extra task which they had to work into an already busy schedule. The thoroughness of the replies indicated that a great deal of care, time, and effort went into their preparation, and showed a real concern that the information submitted be correct, adequate, and to the point.

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## YEAR BOOK CORRECTIONS

The following addition and correction should be made to the 1957 Year Book which was published in the March, 1957 issue of THIS JOURNAL:

**William D. Hatfield Award** (page 334).

Add the name of Gordon Remsburg (Md.).

**Maryland-Delaware Water and Sewage Association—Sewage Works Section** (page 348).

Correct spelling of the name of the Second Vice-President is Earl D. Krapf.

# STREAM IMPROVEMENT PROGRAM FOR A PAPER MILL *

By John K. Sullins

*The Kingsport Division of the Mead Corporation, Kingsport, Tenn.*

The Kingsport Division, one of 13 mills operated by the Mead Corporation, produces uncoated and machine coated white paper. Daily production is about 300 tons of paper and 225 tons of soda pulp, of which 100 tons is dried on a pulp machine and sold. The paper is used in school books, novels, magazines, can labels, etc.

## Pulp and Papermaking Process

The pulp wood is bought either peeled or unpeeled. The peeled wood is conveyed directly to the chippers. The unpeeled or rough wood is debarked in barking drums before being chipped. Chips are stored in bins located above the digesters.

Approximately 60,000 lb. of chips are loaded into the top of each cylindrically-shaped digester, and cooking liquor is added. The cooking liquor or white liquor is composed of sodium hydroxide and some sodium carbonate. Soda pulp derives its name from the sodium hydroxide (caustic soda) used to cook the chips. The proper concentration of the chemicals is adjusted by the addition of black liquor from the brown-stock washer. Chips are cooked indirectly by steam at 100 p.s.i. The cooking liquor is circulated through the digesters during the cooking period. Upon the completion of the cooking process the total charge (pulp and black liquor) is discharged from the bottom of the digester into a blow tank.

The contents of the blow tank, which are considered to be the brown pulp slurry, are pumped from the blow tank through a knotter, where the knots are rejected, to the brown-stock washer. The washer has two continuous cylindrical vacuum filters. The wash water flows countercurrent to the flow of stock. Brown stock comes from the washer almost clean of black liquor. The black liquor from the first stage of the washer is evaporated to about 55 per cent solids in a quintuple-effect evaporator.

This black liquor is burned in the recovery boiler and sodium carbonate smelt is discharged from the bottom of the boiler into a smelt dissolving tank. This smelt liquor or green liquor is causticized with lime in a continuous causticizing system to produce the cooking liquor. The lime mud (calcium carbonate) from the causticizing reaction is washed, concentrated with a centrifuge, and burned in a lime kiln to recover the lime. The weak liquor from the lime mud washing is used for dissolving the smelt at the recovery boiler and for make-up in the digesters.

The brown pulp from the brown-stock washer is screened to remove small shives (splinters of raw fiber not thoroughly reduced in cooking). Bleaching is by the conventional three-stage bleaching system, using a batch process. The first stage of the bleaching process is direct chlorination with chlorine gas. Chlorine reacts with the residual lignin to dissolve it from the unbleached pulp or render it amenable to solution. After chlorination the pulp is washed and subjected to caustic

* Presented at the 1956 Annual Meeting, Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.; Chattanooga, Tenn.; Sept. 17–19, 1956.

extraction. In the second stage of the bleaching process, sodium hydroxide is added to the pulp and the mixture is heated. The chlorinated lignin readily dissolves in a weak alkaline solution, and the pulp is washed again. Most of the color in bleach plant effluents comes from the second-stage washer. The third stage of the bleaching process is the final bleaching with calcium hypochlorite bleach liquor.

After this final wash, part of the pulp goes to the pulp machine and the balance to the paper mill.

The Kingsport Division operates four white paper machines. The different pulps, fillers, dyes and other ingredients are blended in beaters before being fed to two of the paper machines. The other two machines are fed a blended mixture of pulp and ingredients by continuous metering systems.

Coated papers are coated directly on the paper machines. The coated paper leaves the machines dull in appearance, and it is necessary to run the paper through a supercalender to obtain a smooth and glossy appearance.

## Wastes Control

In 1948 the first major step was made to reduce the suspended solids load being discharged to the South Holston River. At this time the suspended solids in the effluent totaled approximately 250,000 lb. per day, broken down as follows:

| Solids | Quantity (lb.) |
|---|---|
| Lime mud | 150,000 |
| Black ash | 55,000 |
| Paper mill sewer losses | 45,000 |

In 1948 the suspended solids discharged through the sewer amounted to 741 lb. per net ton of total mill production of both pulp and paper. Since lime mud constituted the largest single source of suspended solids, a lime kiln was installed to reduce the losses to the river and recover the lime from the lime mud slurry. The lime kiln was placed in operation in November, 1948 and resulted in a suspended solids reduction of 120,000 lb. per day in the mill effluent. Recovery efficiency of the lime kiln at that time was about 80 per cent.

### *Black Ash Char*

The next step in the pollution abatement program was the elimination of black ash char. The soda ash was formerly recovered by burning the concentrated black liquor from pulp washing in a rotating cylinder similar to a lime kiln. Combustion took place in the cylinder but the product, black ash, still contained a considerable quantity of unburned carbon. The soda ash was leached out of the char, and the char was discharged to the sewer. At a soda pulp production of 120 tons per day the char amounted to about 55,000 lb.

A recovery furnace was installed in 1950 to eliminate the black ash char by complete combustion of the black liquor. During 1949 and 1950 dust collectors were installed on three of the coal-fired boilers. These dust collectors discharged fly ash into the sewer at the rate of about 20,000 lb. per day. The net decrease in solids to the river after the installation of the recovery boiler was about 35,000 lb. per day.

### *Suspended Solids*

By 1951 the suspended solids losses in the effluent were reduced approximately 100,000 lb. per day. The breakdown was as follows:

| Solids Source | Quantity (lb.) |
|---|---|
| Lime mud | 10,000–30,000 |
| Fly ash | 15,000–25,000 |
| Paper mill | 40,000–55,000 |

This represented a reduction of 60 per cent from the 1948 level, although total production in the mill increased by 68 tons per day. On a basis of suspended solids losses per net ton of production, a reduction of 66 per cent was obtained compared with the 1948 average.

To further reduce the suspended solids content of the effluent, a settling pond was constructed. Use of the pond was restricted to inorganic wastes to avoid the possibility of decomposition and odors which might result if organic wastes were held in the pond.

The fly ash effluent and the waste from the sewer in the causticizing area, which includes the lime kiln, were diverted to this pond in July, 1954. Suspended solids discharged to this lagoon averaged 50,000 lb. per day.

At about the time the settling pond was constructed a "broke washer" was placed in operation. All scrap paper or broke is re-used in the paper-making system. The coated papers made at this mill have a high percentage of filler and coating. To improve the quality of the broke for re-use, a portion of the filler and coating are removed by the broke washer. Installation of the broke washer reduced the solids from the paper mill from about 50,000 lb. per day to 40,000 lb. per day, but the broke-washing operation showed a loss of about 25,000 lb. per day. As a result, there was a net increase from the paper mill area of approximately 15,000 lb. per day.

Considering the combined effect of the settling pond and the broke washer, the net decrease in effluent suspended solids was 35,000 lb. per day. Since 1955 the suspended solids discharged have averaged 70,000 to 75,000 lb. per day. This represents a reduction of 72 per cent from the 1948 level, when the first major step in the pollution abatement program was taken. Total net mill production, including both pulp and paper, has increased from 332 tons per day in 1948 to 527 tons per day in 1956. The suspended solids discharged to the South Holston River have been reduced from 741 lb. per ton of net production in 1948 to 137 lb. in 1956, or an 82 per cent reduction.

Suspended solids losses in the pulp mill area are now negligible and future reductions will necessarily be realized in the paper mill system. Progress has already been made in this field by closing up to reduce losses.

To obtain a further reduction in suspended solids from the paper mill system it will be necessary to go to some type of clarification. The broke washer losses amounted to 20,000 to 35,000 lb. in a total flow of 0.7 to 0.9 m.g.d., as compared to paper mill sewer losses of 30,000 to 45,000 lb. in a flow of 7 to 9 m.g.d. Because of the smaller volume of flow, treatment of the broke washer effluent is indicated as the next step for possible suspended solids reduction. Tests are now being made on clarification of the broke washer effluent with an experimental 10-ft. clarifier.* Present data are insufficient for definite recommendations, but sludge disposal will be the greatest problem.

Comprehensive tests have been made on the paper mill sewer effluent, but they are not of significance due to the fact that the character of the wastes will change on completion of the new bleach plant, which will have a separate sewer system. Part of the wastes from the present bleach plant are discharged to the paper mill sewer.

Venturi flumes and samplers have been constructed and placed in all sewers where the solids losses are the greatest. One-foot Venturi flumes have been installed in the broke washer and lagoon sewers, and a 2-ft. flume has been installed in the paper mill sewer. The main sewer flow is measured with a 4-ft. venturi flume.

Samplers which collect a sample in direct proportion to the flow are installed in all the flumes except the broke washer sewer. These samplers were designed and constructed at the mill. The broke washer effluent is sampled directly from the line before it enters the sewer. A satisfactory method of obtaining a proportional sample from this line has not been devised.

* Hydrotreater, Dorr-Oliver Inc.

*B.O.D.*

A reduction in the B.O.D. or population equivalent of the mill effluent has been a more difficult problem. Of all the pulp mill wastes, the black liquor from the cooking of the wood has the highest B.O.D. The B.O.D. of the liquor from the digesters has not been determined, but it is estimated that it exceeds 30,000 p.p.m. Prior to 1952 the black liquor was washed from the pulp by displacement with fresh water in false-bottomed tanks or pans. When the black liquor became too dilute for economical evaporation it was diverted to the sewer. In March, 1952, a two-stage countercurrent brown-stock washer was installed. With this type of washer, black liquor losses were eliminated. The brown-stock washer installation resulted in a reduction of the main sewer B.O.D. from 169 p.p.m. in 1951 to 115 p.p.m. in 1952 or, in terms of population equivalents, from 135,000 to 92,000. Since 1952 the B.O.D. has been increasing slowly, due to increased production, but the pollution load, in terms of population equivalents per ton of total production, has been decreasing due to the closing up of systems throughout the mill.

Another factor in the B.O.D. reduction has been the substitution of mannoglactin gum for starch as a fiber bonder in the ratio of 1 lb. of gum for 5 lb. of starch. The B.O.D. of both the gum and the starch is about the same. Installation of the broke washer caused an increase in B.O.D. due to the washing out of more adhesives in the broke than formerly.

For a period the increased pulp production overloaded the black-liquor evaporator, causing a higher loss of black liquor and necessitating the reactivation of an old evaporator. The B.O.D. contributions from this department have since been reduced to a normal level.

Progress in B.O.D. reduction has continued, when expressed in terms of population equivalents per ton of total production. In 1951 the population equivalent per ton of total production was 366, as compared with 244 in 1956. This represents a reduction of 27 per cent.

Of the different methods considered for treatment of organic solids, an activated sludge plant appeared to be the best method for reducing the B.O.D. of the mill effluent.

### Activated Sludge Pilot Plant

In the spring of 1955 an experimental activated sludge plant was installed to study the treatment of the mill wastes. The activated sludge plant was arranged so that it could be operated alone or in combination with the test clarifier. Effluent from the clarifier was discharged directly, either to the sewer or to a 6,000-gal. activated sludge feed storage tank, or to both. The activated sludge feed storage tank also could be supplied with clarified water from the No. 3 paper machine, broke-washer effluent, or a mixture of these two effluents to obtain a wide range in B.O.D. content.

Feed is pumped from the activated sludge feed tank to the aerator headbox in excess of the desired rate, which is controlled by an adjustable slot in the headbox. The excess feed overflows to the feed tank. Recycled sludge from the clarifier and the feed enter the aerator at the same location.

The 1,230-gal. capacity aerator is divided into three sections with an air diffuser pipe in each section. Air flow to the aerator is measured with a Rotometer. The effluent from the aerator overflows to a 6-ft. diameter clarifier with an effective volume of 1,095 gal. The effluent from the activated sludge clarifier overflows into a launder ring, then to the sewer. The clarifier sludge settles and is pumped to the aerator with an air lift; then the excess sludge is diverted intermittingly from the aerator to the sewer.

In terms of B.O.D., the broke washer effluent is the strongest of the mill ef-

fluents and ranges from 500 to 900 p.p.m. The B.O.D. results from starches and other organic compounds in the coated papers, which are washed out on the broke washer.

Seed for the pilot plant was obtained from the Bristol, Tenn., sewage treatment plant. The first feed added was clarified water from the No. 3 paper machine with a B.O.D. of from 40 to 70 p.p.m. This was found to be too low to promote sufficient bacterial growth to produce a satisfactory floc. Broke washer effluent was then added with the clarified paper machine water to increase the B.O.D. to 100 p.p.m. As the floc developed, the B.O.D. of the feed was increased gradually. During the first series of tests, feed having a B.O.D. as high as 900 p.p.m. was successfully treated, but a long aeration time was necessary.

The pilot plant was operated for 11 days at a feed B.O.D. of 896 p.p.m. and an aeration period of 10.3 hr. The removal efficiency was 99.4 per cent. The B.O.D. removed per day per 1,000 cu. ft. of aerator volume was only 20.5 lb., and 1.8 lb. of sludge was produced per pound of B.O.D. removed. The feed B.O.D. was increased to 819 p.p.m. for an additional 11 days of testing and the aeration period was reduced to 8.7 hr.; the efficiency was 97.5 per cent. An average of 33 lb. of B.O.D. was removed per day per 1,000 cu. ft. of aerator volume, and 3.7 lb. of sludge was produced per pound of B.O.D. removed.

The sludge turned anaerobic after four days when the feed rate was increased from 0.6 g.p.m. to 0.9 g.p.m.

Efficiencies of 95 per cent were obtained at feed B.O.D. values of 150 p.p.m. and an aeration period of 2.5 hr. At this rate 72.0 lb. of B.O.D. was removed per day per 1,000 cu. ft. of aerator volume, and 1.8 lb. of sludge was produced per pound of B.O.D. removed.

To date the best results were obtained at an average of 461 p.p.m. of B.O.D. and an aeration period of 4.9 hr. Under these conditions the efficiency was 98 per cent and only 0.31 lb. of sludge was produced per pound of B.O.D. removed. At this rate, 96.5 lb. of B.O.D. was removed per day per 1,000 cu. ft. of aerator volume.

There have been occasions when the activated sludge has gone anaerobic for various reasons. However, it was possible to revive the aerobic bacteria in less than 24 hr. by stopping the feed, and aerating both the aerator and clarifier. A few days are then required to acclimatize the sludge to strong feed again.

The sludge volume index usually is high when using a feed having a B.O.D. of 300 p.p.m. or more, and the efficiency of the unit is good until the index rises above 300.

With the type of feed used, a comparison of alkalinity of the feed and effluent is one of the best control tests. Operation is best when the alkalinity of the effluent is considerably lower than that of the feed. When the alkalinity of the effluent becomes higher than that of the feed trouble can be expected.

The feed is normally turbid and milky in appearance. The effluent is quite clear with a color of 5 to 10 p.p.m. The floc is light tan colored, and the settling rate is slower than with floc from sanitary wastes. The aerator has been operated at a solids content of 3,000 p.p.m.

Present indications are that the broke-washer effluent can be treated by clarification, followed by activated sludge treatment. The sludge from the clarifier and the activated sludge unit can be given anaerobic digestion. Sludge from the clarifier will amount to about 25,000 lb. per day and contain 75 to 90 per cent inorganic solids. Sludge volume from a suitably sized activated sludge plant is estimated to total 6,000 to 12,000 lb. per day. Total sludge volume will amount to about 35,000 lb. per day. Less than one-half the solids will be organic. It may be possible to treat this combination by

anaerobic digestion. Anaerobic digestion tests have not been made to date on this combination of wastes. However, if anaerobic digestion does not work, sludge disposal will be a difficult problem.

### Conclusion

At present the main sewer effluent flow averages 21 m.g.d. With the completion of the new bleach plant the flow will increase to about 25 m.g.d. With future expansion the flow will continue to increase.

It should not be necessary to treat the total flow from the mill in order to treat the wastes. Separate treatment of individual effluents or groups of effluents appears to be the logical approach. This is emphasized by the negligible suspended solids content in the pulp mill effluent, and the fact that with good operation black-liquor losses are small and do not contribute much to the over-all B.O.D. content of the effluent.

At present the quality of the pulp mill wastes is good and should require no additional treatment. Clarification of wastes from the paper mill may be all that is required for treatment. However, a considerable amount of experimental work remains to be done before any additional reduction in pollution load can be accomplished.

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## MEETINGS OF INTEREST

### 1957

Jun. 10–12 **Fourth Ontario Industrial Waste Conference,** Delawana Inn, Honey Harbour, Ontario, Canada. A. E. Berry, Ontario Water Resources Commission, East Block, Parliament Buildings, Toronto, Ontario, Canada.

Jun. 17–21 **Bioxidation of Organic Wastes,** Manhattan College, New York, N. Y. Associate Professor W. W. Eckenfelder, Jr., Civil Engineering Dept., Manhattan College, New York 71, N. Y.

Jun. 24–28 **Seventh Annual Pennsylvania Sewage Works School,** University Park, Pa. Clifford V. Smith, Jr., Dept. of Civil Engineering, Pennsylvania State University, University Park, Pa.

Jul. 1 to Aug. 30 **Nuclear Engineering Short Course.** D. C. Bryant, Administrator, Nuclear Engineering Program, Engineering and Science Extension, Room 100, Building T-11, University of California, Berkeley 4, Calif.

Jul. 8–12 **Nuclear Engineering Survey.** Nuclear Engineering Program, Room 100, Building T-11, University of California, Berkeley 4, Calif.

Aug. 19–23 **Massachusetts Institute of Technology.** Disposal of Industrial Wastes from the Textile Industry. Summer Session, M.I.T., Cambridge 39, Mass.

Aug. 20–22 **Northwestern University.** Liquid scintillation counting. Associate Professor Carlos G. Bell, Jr., Northwestern University, Evanston, Ill.

Sep. 22–25 **Public Works Congress and Equipment Show,** Philadelphia, Pa. Donald F. Herrick, Executive Director, American Public Works Association, 1313 East 60th St., Chicago 37, Ill.

# RADIOACTIVE WASTE PROBLEMS FACING STATE GOVERNMENTS *

By Emil C. Jensen, E. F. Eldridge, Curtiss M. Everts, Jr., and Herbert C. Clare

*Respectively, Chief Sanitary Engineer, Washington State Department of Health; Director, Washington State Pollution Control Commission; Chief Sanitary Engineer, Oregon State Board of Health; and Senior Sanitary Engineer, United States Public Health Service, Portland, Ore.*

State governments are facing a grave challenge in providing adequate controls to prevent harmful radiation exposure in the environment. Their need is to acquire the resources and a period of time in which to develop competence. Their experience to date in this field is considerably short of that which will be required as they take over a major share of the responsibility. The radiation problem associated with the use of radium and X-ray, prior to the recent extensive developments in atomic energy, commanded the attention of relatively few people. And, during the past 10 to 15 years, the states have had very little responsibility and opportunity to become familiar with the factors relating to control of radiation exposure.

The potential benefits of atomic energy should be fully recognized; the goal should be the attainment of radiation protection with minimum restriction on the early development and utilization of these benefits. With the intent of furthering this goal, the authors offer advice and guidance to those who are responsible for assuring the safety of our environment. The discussion is not limited exclusively to problems of radioactive waste treatment and disposal but also deals, in some measure, with other sources of radiation or factors which can result in contamination of the environment and exposure of the public. Some of the states' resources and status of activities pertaining to control are also considered.

## Problems and Challenges

In most discussions on the problem of radiation hazard control, emphasis is usually placed on two factors: (a) the anticipated increase in the use of nuclear materials (for example, by reference to the creation of millions of curies of new fission products each year by power reactors); and (b) the unknown effects of radiation on human beings. There may well be a factor of even greater importance from the standpoint of state government. Often overlooked is the magnitude and complexity of the task faced by state governments during the current transition stage when the emphasis on atoms for peace shifts the responsibility for development from the federal government to private industry. As this occurs, the states, in discharging their traditional responsibility for protection of the environment, will have to assume a major role in the program for radiation protection. There is a real question as to the readiness of many states to accept this challenge.

The records show that the Atomic Energy Commission has achieved a remarkable degree of success in the control of radiation thus far, especially since this was accomplished during a

* Presented at the Second Nuclear Engineering and Science Conference; Philadelphia, Pa.; Mar. 11–14, 1957.

most pressing developmental stage. It remains to be seen whether these conditions will continue to prevail as competitive industries pick up the reins and the industrial economics enters the picture. The federal government has extensive opportunity at the present time, through licensing and inspection programs, to provide controls. But how effective such controls will prove, as the use of nuclear materials increases and extends to all corners of the nation, is still a matter for speculation.

Many new factors must be considered in relation to utilization of water courses for radioactive waste disposal and some aspects of the problem will require a complete change in the usual line of thinking. Some examples are the following:

1. Radioactive characteristics of a waste may demand more than a million times the dilution necessary to nullify other pollutional characteristics. One billionth of a part per million of strontium $^{90}$ would produce tolerance levels.

2. The food chain comes in as a prominent factor. Plankton and algae may absorb the radioactive nutrients directly from the water. Bottom animals feed on this material, fish feed on the animals, and, at the end of the chain, is man. Of particular note is the fact that the plant life has been measured to accumulate or concentrate the radioactivity to a level of over 1,000 times that in the surrounding water. This concentrating effect continues by selective deposition of the radioactivity in certain parts of the fish.

3. Thermal and density conditions require more specific study of factors affecting stream-flow patterns and the dispersion from out-falls. This will be especially important with material having a short half-life. Good initial mixing and dispersion of such material is a major factor in allowing maximum utilization of the receiving water course.

4. The hazardous characteristic of a waste may be carried, practically undiminished, throughout the entire length of a stream. Time is the only factor effecting any reduction in the radioactivity of material remaining in suspension.

5. Radioactivity is removed from solution by certain sediments. This transfers the problem to a consideration of the factors governing their transportation. The result may be a heavy accumulation of radioactivity in sections of the stream bed during low flow; and the flushing of high concentrations during floods.

Excellent discussions related to this phase of the problem are available in papers presented at the first sessions of the Nuclear Engineering and Science Congress in Cleveland in 1955 (1)(2)(3)(4).

The quality of water supplies for nuclear energy plants will be of concern and will represent a means of controlling radiation. Dissolved and suspended matter, especially certain mineral elements, may become irradiated. This will require that attention be given to upstream discharges from such operations as mining, return flows from irrigated areas, and certain industrial plants, in order to control the concentrations of mineral elements.

Disposal of radioactive wastes into community sewer systems and treatment works will present additional problems of concern. It is believed that these will be small in the total picture because the larger sources of radioactive wastes must be handled independently. However, it may be anticipated that some difficulties will be experienced in such matters as (a) concentration of radioactivity in the plant and animal life in the sewer, (b) removal efficiencies at the treatment works, (c) possible concentration in some units of the treatment works, (d) effects beyond the outfall, and (e) personnel safety. This will necessitate such activities as efforts to eliminate

or prevent the sources of wastes, routine monitoring, and, possibly, adjustment of treatment processes. Related problems have been discussed in numerous articles on the measuring of radioactivity in water and factors governing removal in treatment processes (5)(6)(7).

The evaluation of a radioactive water pollution problem requires knowledge of natural background radioactivity, the characteristics of the radioactivity present, and information on the kinds of radioisotopes from the sources of contamination. The work associated with such an evaluation is immense. Moreover, the problem is one of great complexity which is made more complex by the fact that many of the involved procedures are yet to be developed or refined. It will definitely be a responsibility of the sanitary engineer to join with the team in accomplishing this work in the same way that he helped with other waste disposal problems.

*Sea Burial*

Sea burial practices for radioactive wastes are not without hazard. Solidified and encased wastes can be safely buried in very limited areas of the sea floor only. The present practice of dumping such wastes anywhere at sea in the expectation that they will settle into bottom muds and become permanently embedded and covered is inadvisable because sediment deposit and accumulation on most of the ocean floor is very light and the radioactive packages will be subject to eventual disintegration.

Studies have shown that there are very definite limitations and many things are yet to be learned concerning the use of the oceans for disposal of large quantities of liquid waste (1). It is the consensus of informed opinion that apparent large dilution ratios are not generally available because of lack of vertical mixing. Valleys or depressions in the ocean floor, where there is little movement of the water mass, present a possibility for dense concentrations of radioactive waste. However, in the use of such sites over a period of time, the effects of thermal currents would also have to be considered.

*Ground Disposal*

Ground disposal systems for both liquid and solid radioactive wastes present completely different problems than those encountered in the disposal of other wastes because of the long life and stability of some radioactive wastes. The time element to be considered may now be hundreds of years rather than days or months. This brings forth for prominent consideration the often disregardable factor of ground water movement. Some wastes will have to be permanently contained and this will demand that unprecedented attention be given to durability of encasement structures. Others will require study of the fixation ability of the subsoils. In such cases, schemes will have to be devised for the permanent exclusion of the public and any human activity. To provide monitoring over a period of hundreds and perhaps thousands of years will be a considerable undertaking.

## Resources and Status of State Program

In an attempt to find out something about the resources which are available to state governments in handling the problems connected with the treatment and disposal of radioactive wastes and the current status of their present programs, an inquiry was sent to all state sanitary engineers (directors of the divisions of engineering and sanitation of the state health departments) and directors of the state water pollution control agencies where such were separate from the department of health. Admittedly there are many shortcomings in using this approach to evaluate a situation, especially one in which there is so much initial variance.

Differences in the interpretation of a question often lead to a completely different report on two like situations. Additional errors occur in trying to interpret and summarize the answers. However, 50 of the 57 questionnaires sent out were returned and the results to be summarized here are taken from replies received from 44 states and the territories of Alaska and Hawaii. It is believed that some significant and helpful findings were attained from this survey.

*State Government Attitudes*

Of first concern was an appraisal of the sincerity of interest or attitude of state government on the problem and a verification of such by evidence of their activities relating to legislation and control. The replies revealed that:

1. Twenty-two states were placing complete reliance, for the time being, on existing authority within public health and pollution control laws.

2. Only seven states had specific legislative authority. In four of these legislation was statutory and, in three, through regulation of existing authority.

3. Fifteen states indicated that measures were being presented to their legislature or that studies were actively underway on the preparation of material in anticipation of legislation. Some of this latter group were carrying on programs based temporarily on existing authority.

4. Sixteen states apparently had no program or activity. With a few this can be interpreted to mean that there is a complete lack of interest. With the others it can be taken as an indication of lack of time to give or nonexistence of problems demanding attention.

5. Sixteen states reported minor activities such as background surveys, occasional consultations, and some work with AEC on inspection of radioisotope users, and participation in the national air sampling network.

6. Twelve states reported fairly extensive programs including elaborate stream surveys, participation in site selection for nuclear energy plants, inspection and registration of users of radiation, etc.

*Standards for Wastes Discharges*

On the subject of standards for waste discharges, it is of interest to note that the usual independence of state thinking and attitude was lacking. There was a predominance of dependency on the health and safety regulations of the Atomic Energy Commission or the recommendations of the National Committee on Radiation Protection, National Bureau of Standards (8) (9) (10) (11) (12) (13). Many states had little or no comment, indicating this point had not been reached in their considerations. Specific comment, when offered, tended toward very general coverage in law or regulation, with a realization that the matter should be approached cautiously until more is known on the subject. There was also considerable recognition of the need for uniformity that would be assured through use of the AEC regulations.

*Use of Consultation Services*

The replies indicated that extensive use was being made of consultation services from the AEC and their contractors, the U. S. Public Health Service, and the universities and colleges. A few indicated representation on committees with these agencies and reported such to be an excellent method for exchange of views.

*Training*

On the subject of training, replies indicated that 33 had availed themselves of the various training opportunities, especially those conducted by the Public Health Service. It appeared that an all-out effort had been made by about seven states. This included graduate training for key personnel and short course training for

all other persons having any connection with the program, including persons from local health departments. Answers from the other 23 states indicated that the extent of training was quite variable, but that there was at least a recognition of the need and that efforts were being made to meet the need.

*Laboratory Facilities*

The provision of laboratory services seemed to have a low priority. Ten states reported having such facilities available. Three appeared to be adequately equipped for a complete program. Another 7 had minimal facilities, usually set up in connection with occupational radiation protection activities or background level determinations for water supplies and stream surveys. Ten states reported a definite intention to provide laboratory facilities soon.

*Personnel*

The assignment of manpower to the activities, as might be expected, followed the pattern reported previously regarding the extent of actual programs. However, the details on this point give a little more indication of the intensiveness and competence of the state activities. Seventeen states reported having personnel actually assigned specific responsibilities, but, in most cases this was minimal, consisting of one or two part-time persons. Twelve other states indicated that regular employees handled the work as needed.

*Other Problems Reported*

The following are a few of the more significant problems or situations reported as being of concern to the states:

1. Radiation hazards from within military or other classified installations.

2. Desire for authorities to set levels of concentration which are to be regarded as radioactive contamination.

3. The need for knowing all sources of radiation within a state to permit proper evaluation of any problem.

4. Need for an agency to which pollution control authorities may turn for technical advice.

5. Unfounded and unwarranted fears and over-concern on the part of both the public and government agencies.

6. Anticipation of extensive development of power reactors and related process facilities (due to high cost of electrical power) with a result that waste disposal may seriously endanger the ground water, the main source of supply.

7. The need for a "standard analysis service" to check laboratory procedures and assure uniformity of methods and interpretations.

8. Concern regarding the practice of using radioactive tracers in logging oil production.

9. Concern on the indecision with respect to federal versus state jurisdiction, and the lack of agreement between experts on the genetic hazard.

10. A cross connection between a city water supply and the cooling water system of a reactor, a problem probably new in this industry.

11. Concern with wastes other than radioactive wastes; chromium from cooling water from gaseous diffusion-type plant and fluorides from uranium refining.

12. Belief, expressed from one state, that more should be known regarding transportation of radioactive materials having disaster implications.

*Sewage Systems Controls*

From a final question, it appears that there is very little activity among the cities on the control of radioactive waste discharges to sewer systems. Five large cities were reported to have control through provisions in their

sewer use ordinances and to have established monitoring programs.

### Cooperative Effort

There is nothing in this problem which is basically new; however, its solution will require more teamwork than other problems to date. The states are short on competence to handle the technical complexities and the public does not favor the prospect of industry evaluating its own problems and policing itself. For the team approach to work productively, industry must recognize the jurisdiction and responsibility of the states and the states must be as practical and reasonable as the situation will possibly allow.

As an example of the value and workability of such a cooperative effort, the experience of the authors at Hanford, Wash., is cited.

In the early stages of operation of the AEC's Hanford Works on the Columbia River, adjacent communities developed concern over the safety of the installation and possible effects of the operations on the river and the atmosphere. The water supplies for two major cities a short distance downstream were of greatest concern. The public health and pollution control authorities of Oregon and Washington, having responsibility and appreciation for the concern of the communities, approached the management of the installation on the matter. Management was most receptive and asked for suggestions. As a result, a permanent committee of representatives of the two states and the U. S. Public Health Service was established. It is known as the Columbia River Advisory Group.

Following security clearances, periodic meetings were held with the AEC and contractor personnel and the Group was conducted on plant and site survey trips. Thorough briefing on the industrial processes and activities related to waste disposal and radiation control was included. Soon the Group was in a position to make public statements with confidence to the effect that the operations were not creating a hazard in the river or in the atmosphere. Such statements, of course, were much better received by the communities than similar statements made by the AEC or its contractor.

The Columbia River Advisory Group now meets biannually for one- or two-day sessions. Its main interest at the present time is in following the research and developmental work which is being done.

This has been a most profitable undertaking. The Group has had realistic experience on a scale at least equal to large power reactors. It has followed extensive basic research related to many problems in radioactive waste disposal. It has also assisted by advising on design and operation of water treatment facilities and detention basins for the pile-cooling water, and by having knowledge and control of upstream conditions affecting the quality of the river water. The latter was most important because these factors have bearing on the problems of corrosion and irradiation in the reactors.

### State Advisory Committee to AEC

The Atomic Energy Act of 1954 has set the stage for peaceful use of atomic energy. At least for the present, control for radiation protection in licensed facilities is retained at the federal level. In its administration of the law, however, the Atomic Energy Commission has made a sincere effort to consult with the states on matters of radiation protection and has initiated a program which will ultimately provide the basis for a harmonious federal-state relationship in the field of radiological health.

Of concern to many states are the provisions of some of the regulations promulgated by the Commission. It should be pointed out, however, that those regulations which deal with licensing and radiation protection meas-

sures were carefully devised and represent the best thinking on the subject available today. They were subsequently submitted to the states for comment, and were discussed thoroughly with the Commission's Advisory Committee of State Officials. This Committee has been working with the Commission for more than a year in an effort to develop an effective mechanism for close cooperation between the Commission and the states on matters of mutual interest in the field of atomic energy. There exists such a variety of state agencies responsible for radiation protection that one wonders how the Atomic Energy Commission is able to carry on its activities within a state without having some one agency designated as a local coordinator. The liaison work of this Committee, therefore, should be followed closely by the states both now and in the future.

## Immediate Needs

With respect to development of state legislation, it appears extremely important to have uniform laws at least on the technical phases of the problem. Because of the extensive activity in this area it is important to establish: (a) what constitutes a good uniform law on the subject under present circumstances, and (b) how far should state statutes go to control a situation which is presently in the hands of the federal government.

The training of personnel for activity in the field of atomic energy is a prerequisite for a sound program in the field of radioactive waste disposal. In this area the need is for: (a) coordination of training at the federal level; (b) the recruitment of qualified personnel by pollution control agencies; (c) sound financial support for training programs, and (d) opportunity to gain realistic experience in the program.

It is generally recognized that any successful program must have adequate financial support. This is certainly the case with any program for radioactive waste disposal. Necessary expenses for personnel, equipment, laboratory facilities, and operation are especially high in this field. Unfortunately, such programs are usually in competition with other programs for support and money.

## Conclusions

It is important to recognize that atomic energy will have an unprecedented impact on the sanitary engineering profession. It has so affected every other profession it has touched. In such areas as national defense, power generation, medicine, education, and agriculture, it is challenging the greatest minds. In sanitary engineering, there is the problem of controlling the radiation hazard and there is also the definite possibility of developing beneficial applications to further the investigations and solutions of existing problems.

Unfortunately, the axiom, "where there is a will there is a way," may not apply in this situation. The lack of resources within the states, and the fact that they are not being fully geared to handle the problem, is not due to lack of willingness. Budgets are, as usual, a factor. But the biggest deterrent has been the rapid development and complexity of the problem and the requirement for special training. This is not the usual situation. Previously the staffs of the states have been able to pick up new assignments more or less in stride. With a relatively minor assignment in this field, the states have had to relegate the related programs to a secondary position and training efforts have suffered accordingly. In spite of these difficulties, however, there is good reason for the belief that the attitude and cooperative hand of industry, and the control program of the Atomic Energy Commission will allow the states sufficient time to attain competence and resources if they intensify their efforts immediately.

Seldom, if ever, has there been a more favorable situation. Those responsible for the protection of public health by the control of radiation hazards, can be assured that there will be developments which will contribute tremendously to the advancement of their goals. They can have full confidence that they will not have to resort to elaborate procedures to gain public support for their programs. With radiation, the public is already on their side, perhaps to too great an extent. In addition, an extremely wide variety of training opportunities are available.

With this problem, there is a very real possibility that, unless proper precautions are exercised now, succeeding generations (even those who live 5,000 years in the future) may suffer from defects which they may trace to us. States must pick up their share of the load. They must be alert, resourceful, and practical in their approach. They must use all of the technical information and experience at their command to make a careful evaluation of each problem so that its impact on both present and future generations can be determined. The states must also consider their own readiness and the resources available which will enable them to arrive at reasonable and practical solutions to problems of radioactive waste disposal.

## Acknowledgment

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*Editor's Note*—Papers presented at the First Nuclear Engineering and Science Congress, Cleveland, Ohio, are available from the American Institute of Chemical Engineers, 25 West 45th St., New York 36, N. Y.

# Stream Pollution

## TOXICITY TO *GAMBUSIA AFFINIS* OF CERTAIN PURE CHEMICALS IN TURBID WATERS

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Pollution of streams is a constant hazard of oil refinery operations. In Oklahoma the problem is further compounded by the presence of soil in colloidal suspension and by the fact that there is a tremendous fluctuation in the rate and volume of stream flow. During a two-year period between 1954 and 1956 a study was begun into the total effects of pollution on waters of the state. It was felt that, because seasonal and daily fluctuations occur in the composition of waste waters, a proper beginning could be made by determining the toxicity to a common species of fish (*Gambusia affinis*) of the individual chemicals that might appear in the wastes.

The waters are more commonly turbid than clear, and basic information concerning the precipitation of turbidity is also needed. Water from turbid ponds was selected for dilution because it seemed desirable to use water in which relatively large amounts of clay were normally in colloidal suspension. Pond waters also exhibited less fluctuation in chemical composition than stream waters.

The waters of the area remain turbid over long periods of time except as organic materials (such as barnyard manure, hay, weeds from the surrounding fields, and similar materials) have been added to clear the waters. It seemed desirable to determine if small quantities of the chemicals known to be present in refinery wastes would initiate a similar flocculation reaction and thus perform a useful function. The soil in suspension acts somewhat as a buffer and it seemed possible that in otherwise similar water the turbidity might reduce the toxicity to fishes of some of the chemicals.

A list of the chemicals that might occur in refinery wastes was compiled from published information and consultation with refiners. It seemed desirable to determine the individual toxicities of pure chemicals before testing combinations of chemicals with the intent of finally duplicating the composition of various waste streams within the refinery and then of the total effluent.

Within a petroleum refinery some chemicals may be used interchangeably in certain processes, and waste materials are often released in five or more different streams which may require separate treatment. By varying the use of the chemicals during the processing of petroleum products or by the selected combinations of the several waste streams, the chemist can make possible chemical reactions that will reduce the toxicity of the total effluent. The individual chemical or chemicals that contribute most to the lethal effects of a refinery waste may be given special treatment or removed. The result can be more efficient operation of the refinery, as well as a more satisfactory solution to the problem of eliminating the hazard to aquatic life.

### Experimental Methods

The fish selected for the experiments was a livebearer known as the mosquitofish (*Gambusia affinis*). The species is relatively abundant and is easy to maintain in the laboratory. Because

a total of more than 1,500 specimens was used in experiments during the two years, it was important that large numbers of fishes be kept in the laboratory. The fishes were kept in the laboratory for a period of two to three weeks so that they became accustomed to human observers and to the disturbances of test activities. In the natural environment these fishes feed on plankton and small particles of organic matter. In the laboratory plankton and detritus, collected locally, were given to the fishes along with various artificial foods.

The condition of the fishes could easily be determined by the change in body contour with food intake. They were fed as necessary to maintain a healthy condition.

The fishes were all collected from Stillwater Creek in Payne County, Okla., where they encountered turbidity in their normal habitat. Practically all the fishes used were adult females. Since there was a difference in size between males and females, the females were easy to select.

Many cases of a tail-rot disease were observed in the holding tanks. The tail would begin turning white just in front of the fin, the white area progressing rapidly forward until the fish died. The causative agent was not discovered. Many specimens were lost to this disease until it was discovered that a small amount of terramycin sprinkled on the surface of the water would almost completely eliminate further losses from the disease. During the last 18 months of the experimental program, terramycin was added regularly when fishes were first placed in aquaria.

The water used for experimental dilutions and in the control aquaria was brought into the laboratory from two farm ponds. The continued drouth in the area made it necessary to abandon one of the ponds and include a substitute. These ponds had a long history of high turbidity. In both of these ponds local investigations of the fish populations had revealed a very poor growth of fishes. However, fishes were present in both waters. These ponds were quite similar in chemical composition. It is characteristic of this type of turbid water that there is a relatively low alkalinity (usually less than 100 p.p.m. of methyl orange alkalinity). The pH of the water was usually between 7.8 and 8.3, which is approximately average for the area. Some variation of chemical nature occurred with climatic conditions.

The earlier tests were performed at room temperature. Toward the end of the first year air-conditioning units were installed and the temperature remained fairly constant; during the second year, however, the equipment was not adequate to maintain a constant temperature.

The experimental aquaria were cylindrical pyrex jars 12 in. high and 12 in. in diameter. Each jar contained 15 l. of water at the beginning of the test and water was not replaced. The turbid water was carried from the ponds (approximately two miles) in 10-gal. milk cans and immediately emptied into the test aquaria, where it was allowed to cool or warm to room temperature. Artificial aeration from a compressor served to maintain the oxygen level, to mix the chemicals into the water, and to disperse the turbidity-producing soil as long as possible in the mixture. The chemicals were added as "chemically pure" compounds; whenever quantity permitted, all test dilutions were made from the same factory lot.

Ten fishes were used in each aquarium during all experiments and a control aquarium was always maintained with 10 fishes. All fishes were transferred into the test aquaria as soon as the chemical had been mixed into them. The experiments were continued for at least 96 hr. with checks made of the 24-, 48-, 72-, and 96-hr. survivors. In a few cases the chemicals were re-

checked for 144-hr. survivors. The fishes were not fed during tests.

The dilutions selected were based on the progressive bisection of intervals on a logarithmic scale as suggested by Doudoroff *et al.* (10). The dilutions used for all first experiments with a chemical were at 10, 18, 32, 56, and 100 p.p.m. If deaths did not occur within 96 hr. the same series was run between 100 and 1,000 p.p.m. Again if no deaths occurred the same series was used between 1,000 and 10,000 p.p.m. For some chemicals, dilutions were selected up to 56,000 p.p.m.

A median tolerance limit ($TL_m$) was plotted on logarithmic paper when lethal concentrations were included within an experimental range (10). When 24-, 48-, and 96-hr. $TL_m$'s were drastically different they sometimes overlapped between ranges. When this was true suitable dilutions were prepared and the test was re-run so that at least one aquarium would have all living fishes and at least one aquarium would have all dead fishes within 24 hr.

The temperature, turbidity, and pH of the experimental water were measured just after the chemical was added and daily throughout the experiment. An ordinary chemical thermometer was used for temperature readings, turbidity was determined with a Jackson turbidimeter, and pH was determined with a Beckman glass electrode pH meter.

For a special set of experiments to determine if different kinds of turbidity might sometimes be toxic in themselves, subsoil clay was brought to the laboratory from five areas of the state. These soils were selected by a soil specialist as representing the kinds of clays that might become suspended in Oklahoma waters. The soils were brought into the laboratory and mixed into tap water. All larger particles were removed by hand so that only the fine clay remained. The mixing of clay in water was continued for a period of approximately a week in order to produce a turbidity that would remain relatively constant with aeration and in order for the chemical conditions to become stabilized.

At the end of this time 10 fishes were placed in each aquarium and left undisturbed, except for aeration, for 24 hr. so that they might become accustomed to the sometimes drastic change in pH. After 24 hr., more and more of the soil was added daily to the water until finally the concentration of clay was sufficient to kill the fishes. The turbidities of the aquaria would be reduced over night when aeration was the only thing that maintained the suspension. Turbidity was measured each day and, after recording the value, further soil was mixed by hand into the water and the maximum turbidity was recorded. With few exceptions the fishes died while the water was being hand-mixed; the determination of the tolerance limit was thus reasonably accurate.

## Presentation of Data

The experimental data are given for each chemical in alphabetical order in the appendix. Summaries of the data are given in Tables I and II. The $TL_m$ for each chemical is given under the conditions of the data collection, and selected data are included for comparison. More detailed summaries of the literature are given elsewhere (5) (11) (12).

## Resumé of Results

Data were collected on the toxicity of 86 pure chemicals to the mosquitofish (*Gambusia affinis*). Table I lists the toxicity of the chemicals as tested in turbid pond water, as well as information concerning test conditions with regard to turbidity, temperature, and pH. The individual toxicities of these chemicals are mostly of academic interest inasmuch as they would not normally appear as pure chemicals in waste water. They are of interest,

however, as a potential approach to the toxicity of total wastes. It is sometimes true that massive kills of fishes occur in waters whose known components are non-toxic, at least in the quantities known to be present. It is necessary to be aware of all chemicals of potential toxicity in a waste if one is to effectively operate a disposal program.

Many workers have demonstrated that fishes in streams commonly migrate considerably and a fish approaching an area of potentially dangerous pollution would probably die or pass through the questionable water within 96 hr. The long-time and residual effects of cumulative pollution were not studied, as they did not seem to be immediately approachable in an oil refinery waste where the nature of the chemical effluent changes with the source of the crude oil received from day to day; where the refining processes are adjusted to the marketable supply of products; and where the production may vary drastically from one working shift to the next.

A potential use of the data is indicated by the arrangement of chemicals in the order of their decreasing toxicity (Table I). A refiner may use alternative compounds in certain processes, such as clearing the steam boilers of sludge or preventing sludge formation. If he could use either sodium aluminate or barium carbonate in his boiler treatment, a glance at Table I would call attention to the lower toxicity of barium carbonate and thus make possible a less toxic effluent.

The work of Wallen (40) was re-

**TABLE I.—Toxicity to Gambusia of 86 Chemicals Tested in Turbid Waters[1]**

| Chemical | Temp. Range (° C.) | Turb. (p.p.m.) | | pH Range | Median Tolerance Limit, $TL_m$ (p.p.m.)[2] | | | |
|---|---|---|---|---|---|---|---|---|
| | | Init. | Final | | 24 Hr. | 48 Hr. | 96 Hr. | 144 Hr. |
| Acetamide | 21–24 | 370 | 65 | 5.1–8.0 | 26,300 | 26,300 | 13,300(75) | |
| Acetic acid | 16–25 | 169 | <25 | 6.9–8.7 | 251 | 251 | 251(40) | |
| Acetone | 23–27 | 340 | 340 | 8.0–8.5 | 13,500 | 13,000 | 13,000(74) | |
| Aluminum chloride[3] | 20–21 | 230 | <25 | 4.3–7.2 | 145 | 135 | 133(19) | |
| Aluminum sulfate[3] | 19–22 | 180 | <25 | 4.4–7.7 | 440 | 240 | 235(32) | |
| 4-Amino-*m*-toluene-sulfonic acid | 22–24 | 650 | 220 | 6.3–8.4 | 425 | 410 | 375(43) | |
| Ammonium acetate[3] | 23–25 | 1,400 | <25 | 7.6–8.4 | 238 | 238 | 238(33) | |
| Ammonium carbonate | 17–22 | 185 | 180 | 7.9–8.5 | 238 | 238 | 238(34) | |
| Ammonium chloride | 17–21 | 180 | 175 | 7.4–8.1 | 865 | 510 | 490(47) | |
| Ammonium chromate | 19–23 | 195 | 150 | 7.5–7.8 | 350 | 270 | 240(38) | |
| Ammonium dichromate | 18–20 | 220 | 160 | 5.7–7.4 | 223 | 212 | 136(21) | |
| Ammonium hydroxide | 20–26 | 121 | 67 | 8.2–8.8 | 45 | 37 | 37 (7) | |
| Ammonium sulfate[3] | 20–21 | 240 | <25 | 6.3–7.4 | 1,530 | 1,400 | 1,290(56) | |
| Ammonium sulfide | 21 | 350 | 240 | 7.0–8.8 | 248 | 248 | 248(39) | |
| Ammonium sulfite[3] | 20–21 | 220 | <25 | 2.7–6.7 | 240 | 240 | 240(37) | |
| Ammonium thiocyanate | 16–23 | 200 | 190 | 7.4–7.9 | 910 | 420 | 114(16) | |
| *n*-Amyl acetate | 19–28 | 230 | 90 | 8.3–8.5 | 65 | 65 | 65(10) | |
| Barium carbonate | 17–20 | 380 | 140 | 7.6–8.5 | >10,000 | >10,000 | >10,000(70) | |
| Barium chloride[3] | 18–20 | 100 | <25 | 7.1–7.6 | 4,400 | 3,200 | 1,640(60) | |
| Benzene | 20–22 | 700 | 625 | 8.1–8.4 | 395 | 395 | 386(44) | |
| Benzoic acid[3] | 19–21 | 220 | <25 | 3.8–7.0 | 240 | 225 | 180(30) | |
| Boric acid | 20–23 | 250 | 210 | 5.4–7.3 | 18,000 | 10,500 | 5,600(66) | |
| 2-Butanone | 22–24 | 1,000 | 900 | 8.3–8.6 | 5,600 | 5,600 | 5,600(65) | |
| Calcium carbonate | 19–21 | 260 | 35 | 7.7–8.5 | >56,000 | >56,000 | >56,000(83) | |
| Calcium chloride[3] | 20–23 | 320 | <25 | 6.8–7.6 | 13,400 | 13,400 | 13,400(76) | |
| Calcium hydroxide[3] | 21–23 | 800 | <25 | 8.2–8.9 | 240 | 220 | 160(28) | |
| Calcium sulfate | 21–25 | 3,000 | 106 | 7.5–7.7 | >56,000 | >56,000 | >56,000(84) | |
| Carbon disulfide | 18–22 | 390 | 300 | 7.4–8.0 | 162 | 135 | 135(20) | |
| Copper sulfate[3] | 24–27 | 750 | <25 | 6.1–8.1 | 122 | 84 | 75 | 68(11) |
| Cresol | 17–20 | 290 | 200 | 7.3–7.7 | 24 | 24 | 22 (4) | |
| Cupric oxide | 19–21 | 330 | 165 | 7.5–7.8 | >56,000 | >56,000 | >56,000(85) | |
| Cyclohexane | 21–24 | 150 | 115 | 7.4–8.0 | 15,500 | 15,500 | 15,500(77) | |
| Diethanolamine | 21–23 | 185 | 180 | 7.6–10.4 | 1,800 | 1,550 | 1,400 | 560(48) |
| Diethylene glycol | 23–25 | 1,500 | 600 | 7.9–8.5 | >32,000 | >32,000 | >32,000(82) | |
| Ferric chloride[3] | 21–24 | 350 | <25 | 3.7–7.7 | 74 | 74 | 74(13) | |
| Ferric sulfate[3] | 19–23 | 330 | <25 | 2.6–6.9 | 133 | 133 | 133(18) | |
| Ferrous oxide | 16–23 | 190 | 155 | 7.2–7.9 | >10,000 | >10,000 | >10,000(71) | |
| Ferrous sulfide | 20–26 | 116 | <25 | 8.1–8.4 | >10,000 | >10,000 | >10,000(72) | |
| Ferrous sulfite[3] | 20–21 | 100 | <25 | 3.2–6.9 | 350 | 350 | 350(42) | |
| Furfural | 23–24 | 3,000 | 280 | 7.7–8.5 | 44 | 24 | 24 (5) | |
| Heptane | 20–27 | 126 | 41 | 7.8–8.9 | 4,924 | 4,924 | 4,924(64) | |
| Hydrochloric acid[3] | 21–23 | 114 | <25 | 6.0–8.2 | 282 | 282 | 282(41) | |
| Lead nitrate[3] | 22–24 | 1,600 | <25 | 7.7–8.3 | 240 | 240 | 240(36) | |
| Lead oxide | 18–20 | 315 | 300 | 7.1–7.2 | >56,000 | >56,000 | >56,000(86) | |

TABLE I.—Toxicity to Gambusia of 86 Chemicals Tested in Turbid Waters[1] (Continued)

| Chemical | Temp. Range (° C.) | Turb. (p.p.m.) | | pH Range | Median Tolerance Limit, $TL_m$ (p.p.m.)[2] | | | |
|---|---|---|---|---|---|---|---|---|
| | | Init. | Final | | 24 Hr. | 48 Hr. | 96 Hr. | 144 Hr. |
| Magnesium chloride[3] | 20–24 | 170 | <25 | 7.0–9.1 | 18,750 | 17,750 | 16,500(79) | |
| Magnesium sulfate | 20–25 | 420 | 56 | 7.5–7.7 | 15,500 | 15,500 | 15,500(78) | |
| Maleic anhydride[3] | 20–23 | 128 | <25 | 5.8–8.0 | 240 | 240 | 230(31) | |
| Naphthalene | 22–24 | 320 | 252 | 8.1–8.5 | 220 | 165 | 150(26) | |
| Nitric acid | 19–22 | 205 | 130 | 3.6–7.3 | 75 | 75 | 72(12) | |
| Phenol | 23–26 | 550 | 490 | 7.9–8.5 | 61 | 56 | 56 (9) | |
| Phosphoric acid[3] | 22–24 | 600 | <25 | 4.2–7.9 | 138 | 138 | 138(22) | |
| Potassium chloride | 18–20 | 250 | 94 | 7.4–7.7 | 10,000 | 4,200 | 920(53) | |
| Potassium chromate | 17–21 | 195 | 170 | 7.6–8.1 | 722 | 480 | 400(45) | |
| Potassium cyanide | 21–23 | 200 | 105 | 8.4–8.7 | 1.6 | 1.6 | 1.6 (1) | |
| Potassium dichromate[3] | 21–23 | 1,500 | 55 | 5.4–6.7 | 370 | 320 | 280 | 140(24) |
| Potassium hydroxide | 18–19 | 117 | 55 | 7.3–10.3 | 85 | 80 | 80(14) | |
| Potassium nitrate[3] | 18–22 | 140 | <25 | 7.0–7.4 | 421 | 224 | 162(29) | |
| Potassium permanganate[3] | 21–24 | 360 | <25 | 8.3–8.5 | 12 | 12 | 12 (3) | |
| Potassium phosphate[3] | 20–30 | 75 | <25 | 8.4–11.3 | 750 | 750 | 750(52) | |
| Pyridine | 21–25 | 500 | 320 | 7.7–8.5 | 1,350 | 1,350 | 1,300(57) | |
| Sodium aluminate[3] | 17–19 | 85 | <25 | 8.0–9.4 | 199 | 126 | 111(15) | |
| Sodium bicarbonate | 20–22 | 200 | 185 | 7.3–9.2 | 7,700 | 7,550 | 7,550(68) | |
| Sodium bisulfite[3] | 17–22 | 135 | <25 | 2.9–7.1 | 240 | 240 | 240(35) | |
| Sodium borate | 22–26 | 650 | 410 | 8.6–9.1 | 12,000 | 8,200 | 3,600 | 1,900(61) |
| Sodium carbonate | 18–25 | 160 | 105 | 8.6–9.2 | 1,200 | 840 | 740(50) | |
| Sodium chloride[3] | 20–23 | 230 | <25 | 6.8–7.5 | 18,100 | 18,100 | 17,550(80) | |
| Sodium chromate | 20–22 | 280 | 260 | 7.7–8.6 | 750 | 500 | 420(46) | |
| Sodium dichromate | 24–27 | 650 | 100 | 6.0–7.9 | 460 | 420 | 264 | 146(25) |
| Sodium fluoride[3] | 21–24 | 150 | <25 | 7.5–8.1 | 1,240 | 925 | 925(54) | |
| Sodium hydrosulfide | 21–23 | 1,500 | 350 | 3.7–9.1 | 206 | 206 | 206 | 138(23) |
| Sodium hydroxide | 22–24 | 1,000 | 550 | 8.3–9.0 | 125 | 125 | 125(17) | |
| Sodium nitrate | 19–20 | 280 | 250 | 7.0–7.3 | 11,800 | 10,000 | 6,650(67) | |
| Sodium nitrite | 21–24 | 120 | 140 | 7.1–7.5 | 8.1 | 7.5 | 7.5 (2) | |
| Sodium oxalate | 19–23 | 200 | 165 | 7.5–8.7 | 1,350 | 1,350 | 1,350(58) | |
| Sodium phosphate | 19–23 | 265 | 65 | 7.6–11.0 | 720 | 720 | 720(49) | |
| Sodium pyrophosphate | 19–24 | 260 | 180 | 8.2–9.8 | 1,380 | 1,380 | 1,380(59) | |
| Sodium silicate | 21–22 | 110 | 110 | 8.9–10.1 | 3,200 | 2,400 | 2,320(62) | |
| Sodium sulfate[3] | 22–25 | 650 | <25 | 7.0–8.8 | 24,000 | 17,500 | 16,500 | 10,000(69) |
| Sodium sulfide | 21–25 | 460 | 37 | 7.6–11.0 | 750 | 750 | 750(51) | |
| Sodium sulfite | 18–26 | 98 | 26 | 7.1–7.9 | 2,600 | 2,600 | 2,600(63) | |
| Sodium thiosulfate[3] | 22–24 | 190 | <25 | 6.9–8.9 | 26,400 | 26,000 | 24,000(81) | |
| Sodium triphosphate | 17–22 | 150 | 70 | 7.4–10.3 | 467 | 467 | 151(27) | |
| Sulfur | 20–22 | 200 | 175 | 7.2–7.3 | >10,000 | >10,000 | >10,000(73) | |
| Sulfuric acid | 20–24 | 1,700 | 47 | 6.7–8.2 | 42 | 42 | 42( 8) | |
| Tannic acid | 19–22 | 135 | 170 | 6.7–7.3 | 41 | 41 | 37 (6) | |
| Toluene | 17–22 | 150 | 100 | 7.5–8.5 | 1,340 | 1,260 | 1,180(55) | |

[1] Data are for the series of tests that provided the $TL_m$ in each case.
[2] Numbers in parentheses give order of toxicity in total list.
[3] Settles turbidity.

assessed by a series of tests with clays that produce turbidity in Oklahoma. Subsoil clay was collected from five representative places in Oklahoma that the State Soil Survey indicated would provide a range of types of clay. Duplicate experiments were conducted with several species of fishes to determine if the different soil types would change the direct toxicity of the clay.

Some representative results are shown in Table II. It may be noted that three of the soils were alkaline and two were acid in reaction. In all cases the "turbidity range in which fishes lived" includes maximum turbidities in which the fishes remained alive for at least 2 hr. while being actively stirred by hand. The minimum turbidities were the minimum residual values after the water had settled as much as it would during the usual 24-hr. period between hand-mixing. No food was added to the aquaria, because food would reduce turbidity; after 14 days the fishes were getting thin.

It seemed desirable to mix in sufficient soil to kill all fishes. Therefore, the waters were hand-mixed until all fishes were dead. Even in the water with the lowest pH, where the clay took on a jelly-like consistency at the higher turbidities, the fishes survived in turbidities far greater than the maximum turbidity (18,000 p.p.m.) recorded for the state (29) and the maximum turbidity listed for any area (48,400 p.p.m.) (15). Certainly the highest turbidity of water used in the present experiments (3,000 p.p.m.) should not have produced direct effects

**TABLE II.—Selected Data on Levels of Five Kinds of Turbidity that are Tolerable to Fishes**

| Source of Clay Used[1] | Fishes (No.) | Water Temp. (° C.) | pH | Turbidity in which Fishes Lived (p.p.m.) | Time Fishes Lived (days) | Turbidity at which Fishes Died | |
|---|---|---|---|---|---|---|---|
| | | | | | | (p.p.m.) | Time (hr.) |
| Kiowa County | 10 | 19.5–22.5 | 7.4–7.8 | 30,000–260,000 | 14 | 270,000 | 2 |
| | 10 | 19.5–22.5 | 7.4–7.7 | 85,000–260,000 | 7 | 270,000 | 2 |
| | 10 | 19.5–22.5 | 7.4–8.0 | 12,000–220,000 | 14 | 270,000 | 2 |
| Texas County | 9 | 19–22.5 | 8.0–8.4 | 1,700–240,000 | 14 | 260,000 | 1½ |
| | 9 | 19–22.5 | 8.1–8.2 | 92,000–240,000 | 2 | 260,000 | 1½ |
| | 10 | 19–22.5 | 8.0–8.3 | 1,000–240,000 | 14 | 260,000 | 1½ |
| | 10 | 19–22.5 | 8.2–8.3 | 15,000–240,000 | 6 | 260,000 | 1½ |
| Lincoln County | 7 | 19.5–22.5 | 7.6–8.3 | 5,500–320,000 | 14 | 400,000 | 1½ |
| | 7 | 19.5–22.5 | 7.6–8.2 | 45,000–320,000 | 3 | 400,000 | 1½ |
| | 8 | 20–23 | 7.3–8.2 | 680–220,000 | 14 | 400,000 | 1½ |
| Mayes County | 8 | 21–22 | 5.9–6.6 | 28,000–190,000 | 12 | 360,000 | 1½ |
| | 3 | 20–22 | 5.8–6.6 | 28,000–280,000 | 14 | 360,000 | 1½ |
| | 3 | 20–22 | 5.8–6.4 | 90,000–280,000 | 10 | 360,000 | 1½ |
| | 5 | 20–22.5 | 5.6–7.0 | 16,300–240,000 | 14 | 360,000 | 1½ |
| | 5 | 20–22 | 5.6–6.3 | 100,000–240,000 | 6 | 360,000 | 1½ |
| Choctaw County | 8 | 19.5–22.5 | 4.8–5.4 | 600–160,000 | 14 | 320,000 | 1 |
| | 8 | 19.5–22.5 | 4.6–5.6 | 1,000–160,000 | 14 | 320,000 | 1¼ |

[1] Oklahoma clays used in producing turbidity.

on the fishes during the time of exposure.

To give direction to future immediate needs for study, Table III has been compiled. It lists 55 additional chemicals that are known to be potential components of refinery wastes. Data on the toxicity of some of these chemicals are given elsewhere (5)(11)(12).

In these experiments 29 potential components of refinery wastes that precipitate turbidity were found. The mechanism of removal was not determined. It is noteworthy that the water remained clear after precipitation in these aquaria despite agitation of the water due to the presence of fishes and in the presence of bubbling aeration that mixed the water. Although some of the precipitation was clearly due to a change in pH of the water, as explained by Irwin and Stevenson (25) many of the chemicals seemed to have been effective in removing turbidity with little or no effect on the pH. It is obvious that further study of this relationship is needed.

An additional problem concerns the range of chemical concentration that resulted in precipitation of the turbidity and that killing fishes. It was often true that fishes were killed and turbidity was precipitated in one aquarium, while in the next lower concentration of chemical the fishes remained alive and the turbidity remained sus-

**TABLE III.—Chemicals That May Appear in Refinery Wastes But for Which Toxicity Was Not Tested**

| | | | |
|---|---|---|---|
| Amino quinoline | Diallyl ether | Naphthalic acid | Sodium hypochlorite |
| Ammonium cyanide | Diamyl amine | Orthocresol | Sodium metaphosphate |
| Ammonium ferrocyanide | Dichlorohydrin | Paracresol | Sodium naphthenate |
| Ammonium nitrate | Dipropyl amine | Pentane | Sodium pentachlorophenate |
| Ammonium polysulfide | Epichlorohydrin | Pentene | Sodium phenolate |
| Amyl mercaptan | Ethyl mercaptan | Phlobotannin | Sodium plumbite |
| Barium hydroxide | Ferric hydroxide | Potassium xanthogenate | Sodium tetrabasic phosphate |
| Bromine | Gallotannin | Pyridene sulfonic acid | Sodium thioarsenate |
| Chloramines | Graphite | Pyrogallal | Tannin |
| Cresylic acid | Isopropyl ether | Quinolines | Tetraethyl lead |
| Cryolite | Lead sulfide | Silicon | Thiophene |
| Cyclohexane-carboxylic acid | Magnesium chlorate | Sodium butyl mercaptide | Trichloropropane |
| Cyclohexene | Metacresol | Sodium cresylate | Xylene |
| | Monomethyl amine | Sodium dibasic phosphate | Zeolite |

pended. No adequate explanation of this fact is now available.

In other aquaria an interesting problem was also posed. The turbidity was sometimes precipitated with no noticeable effect on the fishes at the corresponding level. The addition of these chemicals in controlled concentration to natural waters would be a boost to the economy where clear water produces more fishes and encourages more recreational use of the water.

It is also important to determine if variations in concentrations of turbidity would significantly affect the toxicity of a chemical under otherwise similar conditions, especially with those 29 chemicals that reacted to remove the turbidity.

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## APPENDIX—SUMMARY OF EXPERIMENTAL DATA

**Acetamide**—$CH_3 \cdot CO \cdot NH_2$: Between 10 and 10,000 p.p.m. the fishes seemed to survive with no ill effects; at 15,500 and 21,000 p.p.m. they remained essentially normal for 72 hr.; at 96 hr. all were dead. At 24,000 and 42,000 p.p.m. they died in about 5 hr., floating at the top, covered with mucus. Up to 10,000 p.p.m. had no noticeable effect on pH. At the higher concentrations pH was reduced slightly and remained relatively constant during the experiments. Turbidity was not significantly affected. The 96-hr. $TL_m$ was 13,300 p.p.m.

**Acetic acid**—$CH_3 \cdot COOH$: Fishes transferred to concentrations between 100 and 1,000 p.p.m. began swimming frantically. At 100 and 180 p.p.m. they apparently returned to normal in 24 hr. At 320 p.p.m. and higher all were dead at 24 hr.; the water contained strands of mucus and the fishes were completely covered with clinging mucus. Up to 180 p.p.m. turbidity remained the same or was only slightly reduced. With 320 p.p.m. or more turbidity was precipitated during the first 24 hr. to less than 25 p.p.m. (apparently clear). The 96-hr. $TL_m$ (251 p.p.m.), compares with 100 to 200 p.p.m. listed as critical for creek chub (18), and 100 p.p.m. that killed some goldfishes (14).

**Acetone**—$CH_3 \cdot CO \cdot CH_3$: Below 11,500 p.p.m. the fishes showed no permanent distress. At 11,500 p.p.m. they were sluggish and stayed at the surface for most of the first 24 hr. At 15,500 p.p.m. they surfaced for a time, then moved to the bottom and died. They were quite limp and darkly pigmented. There was evidence of loss of equilibrium. This chemical produced no noticeable effect on the turbidity. As compared to the 96-hr. $TL_m$ (13,000 p.p.m.), 14,250 to 15,050 p.p.m. was lethal to the orange spotted sunfish (*Lepomis humilis*) (35).

**Aluminum chloride**—$AlCl_3$ and $AlCl_3 \cdot 6H_2O$: All fishes remained normal in 100 p.p.m. or less. At 180 p.p.m. and higher, they began to secrete quantities of mucus shortly after being placed in the solution and within 24 hr. all were dead. At 1,000 p.p.m. all were dead in 8 hr., at 560 p.p.m. in 14 hr., at 320 p.p.m. in 24 hr. Although all were killed at 180 p.p.m. and turbidity was precipitated, turbidity was also precipitated at 100 p.p.m. in 24 hr. and no fishes were killed, whereas at 56 and 32 p.p.m. turbidity was reduced to approximately one-fourth with no noticeable effects. At 10 and 18 p.p.m. there was no effect on turbidity. As compared with the 96-hr. $TL_m$ (133 p.p.m.), 88 p.p.m. killed some marine fishes (including the redfish), while 132 and 176 p.p.m. killed all fishes tested (32).

**Aluminum sulfate**—$Al_2(SO_4)_3$: At 560 and 1,000 p.p.m. all fishes were killed in 24 hr. In 320 p.p.m. three were killed in 24 hr. and all were dead in 48 hr. In 180 p.p.m. one was dead in 48 hr., the rest were in good condition at the end of the test. At 560 p.p.m. and higher turbidity was cleared in 48 hr. At 320 p.p.m. the water was clear in 72 hr. At 100 p.p.m. and less turbidity did not seem to be affected, whereas at 180 p.p.m. turbidity after 96 hr. was reduced to one-sixth its former concentration. As compared with the 96-hr. $TL_m$ (235 p.p.m.), 250 p.p.m. killed goldfishes, bass, and sunfishes (33).

**4-Amino-m-toluene-sulfonic acid** — $C_7H_6 \cdot NH_2 \cdot SO_3H$: In 180 p.p.m. and less the fishes were apparently normal. At 320 p.p.m. one was dead in 48 hr., two in 72 hr., a fourth in 96 hr., and the remainder seemed in poor condition when removed. At 560 and 1,000 p.p.m. all were dead in 6 hr. The turbidity did not seem particularly affected although the pH was lowered to slightly less than 6.4. The 96-hr. $TL_m$ was 375 p.p.m.

**Ammonium acetate**—$NH_4C_2H_3O_2$: At 180 p.p.m. and below all fishes seemed to survive with no ill effects. At 320 p.p.m. two were dead in 8 hr. and all in 24 hr. At 560 and 1,000 p.p.m. all died in 8 hr. and sank. When removed they were very limp. Although the pH remained approximately constant, in 1,000 p.p.m. the turbidity was reduced from 2,000 p.p.m. to 25 p.p.m., and to a somewhat lesser extent in 100 p.p.m. or more. The 96-hr. $TL_m$ was 238 p.p.m.

**Ammonium carbonate** — $(NH_4)_2CO_3$: Although all fishes were normal up to 180 p.p.m., nine were dead in 5 hr. at 320 p.p.m. and the other was soon dead. There was no noticeable effect on the turbidity. As compared to the 96-hr. $TL_m$ (238 p.p.m.), 155 to 197 p.p.m. killed shiners (7) and 240 p.p.m. killed goldfishes (6).

**Ammonium chloride**—$NH_4Cl$: At 180 p.p.m. and lower no reaction was noticed. At 320 p.p.m. the fishes were very sluggish for slightly over 24 hr., then became essentially normal. In 560 p.p.m. two were dead in 24 hr., four others were dead in 48 hr. and another was dead at 72 hr. After 96 hr. the remaining three appeared normal. At 1,000 p.p.m. five fishes died in 24 hr.; two others were dead in 48 hr.; the remaining three were sluggish but still alive after 96 hr. The turbidity was not affected. As compared to the 96-hr. $TL_m$ (490 p.p.m.), 6 to 7.7 p.p.m. was reported for the bluegill (30), 268 p.p.m. killed goldfishes (14), and 160 p.p.m. is limiting to rainbow trout (36).

**Ammonium chromate**—$(NH_4)_2CrO_4$: At 180 p.p.m. and less all fishes remained normal. With 320 p.p.m. four were dead in 24 hr., three in 48 hr., and all at 72 hr. At 560 p.p.m. and higher all were dead in 24 hr. When dead the fishes floated. While showing the effect of acute toxicity the fishes became less and less active until they finally floated on their sides and died. No effect on the turbidity was apparent. The 96-hr. $TL_m$ was 240 p.p.m.

**Ammonium dichromate**—$(NH_4)_2Cr_2O_7$: Results were not as definite as with most of the other chemicals. Although less than one-half the fishes were killed in 96 hr., three died at 100 p.p.m., three at 56, one at 32, and one at 18 p.p.m. Although deaths may have been due to improper treatment or diseases, deaths at these low concentrations occurred in each case between the 48- and 72-hr. observations. With 180 p.p.m. one fish was dead the first day, two died the second day, two the third day, and two the fourth day; the three removed at the end seemed in satisfactory condition. At 320 p.p.m. all were dead in 24 hr.; at the two higher concentrations all were dead in 4 hr. Reduction in pH was noted at 180 p.p.m. and a further reduction at each of the higher concentrations, with a minimum pH of 5.7. Turbidity was relatively constant throughout. The 96-hr. $TL_m$ was 136 p.p.m.

**Ammonium hydroxide**—$NH_4OH$: At 32 p.p.m. and less no noticeable effect was produced on the fishes. At 56 p.p.m. six were dead in 24 hr. and the rest in 48 hr.; at 100 p.p.m. all were dead in 4 hr. Loss of equilibrium and erratic swimming gave evidence of imminent death. Dead fishes were discolored and very limp. There was no special effect on turbidity. As compared with the 96-hr. $TL_m$ (37 p.p.m.), 7.5 p.p.m. was reported as a 48-hr. $TL_m$ (38) and a critical range for creek chub was 5 to 15 p.p.m. (18).

**Ammonium sulfate**—$(NH_4)_2SO_4$: All fishes were apparently normal at 1,000 p.p.m. or less. With 1,800 p.p.m. seven were dead in 24 hr., one other in 48 hr., and although apparently normal at 72 hr. the remaining two were dead at 96 hr. At 3,200 p.p.m. three were dead in 24 hr. and the remainder in 48 hr. With 5,600 and 10,000 p.p.m. all were dead in 24 hr. The pH was slightly decreased with increased concentration. The minimum pH was 6.6 when all fishes died. At 5,600 p.p.m. turbidity was reduced to approximately one-eighth its former concentration; at 10,000 p.p.m. it was completely precipitated. As compared with the 96-hr. $TL_m$ (1,290 p.p.m.), 264 p.p.m. was lethal to goldfishes in 6 days (14).

**Ammonium sulfide**—$(NH_4)_2S$: In less than 180 p.p.m. all fishes were apparently normal. In 320 p.p.m. eight were dead in 3 hr., the remaining two were near death; 4 hr. later one more was dead and the other seemed normal at 96 hr. In higher concentrations the fishes were soon killed, being dead in 10 min. at 1,000 p.p.m. The fishes were quite limp, but no excess secretion of mucus was noted. Turbidity was not obviously affected. As compared with the 96-hr. $TL_m$ (248 p.p.m.), 100 p.p.m. in hard water killed goldfishes in 72 hr. (14).

**Ammonium sulfite**—$(NH_4)_2SO_3 \cdot H_2O$: All fishes seemed normal at less than 180 p.p.m. At 320 p.p.m. all were dead in 8 hr. They lost equilibrium and surfaced when near death. At 180 p.p.m., turbidity was reduced slightly more than in the lower concentrations, but was not precipitated. At 320 p.p.m. and higher all turbidity was removed

in 24 hr. More than 100 p.p.m. lowered the pH. Although the fishes seemed to remain normal, at 180 p.p.m. the pH was reduced to 4.6 in 48 hr. and remained within 0.1 of this value throughout. The pH could have been lethal in the higher concentrations since it was reduced to between 2.7 and 3.5. The 96-hr. $TL_m$ was 240 p.p.m.

**Ammonium thiocyanate**—$NH_4SCN$: Relatively low immediate toxicity was indicated, but fishes were killed throughout 144 hr. The 96-hr. $TL_m$ does not reveal that all died at 56 p.p.m. after 144 hr. Unfortunately a 144-hr. $TL_m$ is not available. To produce toxicities in 24 hr. and to have all fishes alive in one aquarium after 96 hr., the experiments were repeated five times and the data composited. Most fishes became very darkly pigmented and quite sluggish before death. Determination of the exact time of death was not easy; even at 1,800 p.p.m. only three fishes were dead within 4½ hr. and all were dead only after nearly 24 hr. No noticeable change occurred in turbidity at any concentration except possibly at 3,200 p.p.m. As compared to the 96-hr. $TL_m$ (114 p.p.m.), 280 to 300 p.p.m. in tap water killed orange-spotted sunfishes in 1 hr. (35) and 200 p.p.m. was lethal for fishes (9).

***n*-Amyl acetate**—$CH_3 \cdot CO_2 \cdot C_5H_{11}$: All fishes were normal at 56 p.p.m. and lower; at 100 p.p.m. all were dead in 24 hr. They avoided the aerators where the bubbles became distinctly smaller after addition of the chemical. Eight were dead in 1½ hr. and dead fishes seemed to be especially limp. At 100 p.p.m. turbidity was reduced to less than one-half its former concentration. As compared to the 96-hr. $TL_m$ (65 p.p.m.), 50 to 120 p.p.m. was the critical range for creek chub (18).

**Barium carbonate**—$BaCO_3$: Although two fishes were dead at 10,000 p.p.m., they showed no special symptoms of poisoning and it seems likely that the $TL_m$ is considerably higher. No significant change occurred in either pH or turbidity. The 96-hr. $TL_m$ was greater than 10,000 p.p.m.

**Barium chloride**—$BaCl_2$: All fishes were normal at 100 p.p.m. or less; at 180 and 320 p.p.m. one was dead at 72 hr.; at 560 p.p.m. three were dead at 72 hr.; at 1,000 p.p.m. one was dead at 72 hr. and another at 96 hr. At 1,800 p.p.m. six fishes died between 72 and 96 hr. At 3,200 p.p.m. five were dead at 48 hr., three more at 72 hr., and the remainder in 96 hr. At 5,600 p.p.m. nine were dead after 24 hr. and all in 48 hr. At 10,000 p.p.m. all were dead in 24 hr. Turbidity was precipitated to less than 25 p.p.m. with 180 p.p.m. and higher at approximately the same time as the death of the fishes. There seemed to be a definite relationship between precipitation of turbidity and death of fishes. As compared with the 96-hr. $TL_m$ (1,640 p.p.m.), 5,000 p.p.m. in distilled water killed goldfishes in 12 to 17 hr. (31).

**Benzene**—$C_6H_6$: At 300 p.p.m. and less the fishes were apparently normal. With 560 p.p.m. eight were dead in 3 hr.; the two remaining were still alive at 96 hr. At 1,000 p.p.m. all were dead in 16 min. Dead fishes were quite rigid. Benzene is so volatile that most of it would have disappeared within a short time so the toxicity should have been quickly removed. The 96-hr. $TL_m$ was 386 p.p.m.; the 48-hr. $TL_m$ for the black bullhead (*Ameiurus melas*) was 1,580 p.p.m. Since benzene is more soluble when mixed with acetone, one series was run with 40 per cent benzene in acetone; the 48-hr. $TL_m$ for the black bullhead was 780 p.p.m.

**Benzoic acid**—$C_7H_6O_2$: No toxic effects were noted at 56 p.p.m. or less. In 100 and 180 p.p.m. the fishes developed symptoms of harmful effects during the second day and thereafter were in poor condition but lived through the experiments. At 320 p.p.m. all were dead in 25 min.; at higher concentrations all were dead in 10 min. Turbidity remained constant at 180 p.p.m. or less, but was precipitated at 320 p.p.m. and greater, in each case in 24 hr. The pH was reduced approximately one unit (to 6.3 to 6.7) in 180 p.p.m. In 320 p.p.m., pH was between 4.3 and 4.5; it was slightly lower (to 3.7) in the higher concentrations. As compared to the 96-hr. $TL_m$ (180 p.p.m.), 200 p.p.m. in hard water killed goldfish in 7 to 96 hr. (14) and 550 to 570 p.p.m. in tap water killed orange-spotted sunfishes (35).

**Boric acid**—$H_3BO_3$: At 24,000 p.p.m. seven fishes were killed in 24 hr.; all were killed in 48 hr. At 18,000 p.p.m. five were killed in 24 hr.; the other five in 48 hr. At 10,000 p.p.m. five were killed in 24 hr., none in the second 24 hr., but all were dead in 96 hr. At 5,600 p.p.m. none were killed in 48 hr., but five were dead at 96 hr. At 3,200 p.p.m. two were killed in 96 hr. It was only when concentrations were at 1,800 p.p.m. and less all remained normal for 96 hr. The pH was reduced from 7.6 to 5.6 in the higher concentrations. Turbidity was not reduced. As compared to the 96-hr. $TL_m$ (5,600 p.p.m.), 6,250 p.p.m. killed rudd and roach (45).

**2-Butanone** (Methyl ethyl ketone)—$CH_3COC_2H_5$: All fishes were normal in 3,200 p.p.m. and less. At 5,600 p.p.m. five were dead in 25 min. Although one floated on its side, it was still alive at 96 hr. and the other four remained in good condition. At 10,000 p.p.m. all were dead in 15 min., took on a very dark appearance, and sank. Turbidity was not affected. The 96-hr. $TL_m$ was 5,600 p.p.m.

**Calcium carbonate**—$CaCO_3$: At 10 to 56,000 p.p.m. all fishes remained in good condition. None died between 1,800 and 56,000 p.p.m. At 32,000 and 56,000 p.p.m. the turbidity was markedly reduced (to 63 and 35 p.p.m.), but never completely precipitated. The 96-hr. $TL_m$ was greater than 56,000 p.p.m.

**Calcium chloride**—$CaCl_2$: At 10,000 p.p.m. and less all fishes remained normal. At 18,000 p.p.m. all were dead in 7½ hr., and at 24,000 p.p.m. all were dead in 1 hr. In these two higher concentrations turbidity was precipitated and the water remained clear. At 10,000 p.p.m. the turbidity was precipitated at 24 hr. and again at 72 hr. Turbidity was re-suspended on alternate days and at the end was very little different from at the beginning. As compared with the 96-hr. $TL_m$ (13,400 p.p.m.), a 96-hr. $TL_m$ for small and medium sized bluegills was fixed at 9,500 p.p.m., while 13,300 p.p.m. was the $TL_m$ for large bluegills (30). Bream survived 48-hr. immersion in 10,000 p.p.m. (44).

**Calcium hydroxide**—$Ca(OH)_2$: All fishes were normal at 100 p.p.m. and less. At 180 p.p.m. they secreted quantities of mucus, but seemed fairly normal at 24 hr. At 48 hr. five were dead; at 96 hr. one more was dead and another was quite inactive. At 320 p.p.m. and higher all were dead in 24 hr. At 100 p.p.m. and less turbidity was not significantly changed; at 180 p.p.m. it was reduced by approximately three-fourths; at 320 p.p.m. and more, it was precipitated in 24 hr. Secretion of mucus was especially characteristic and precipitation of turbidity was particularly rapid at introduction of the chemical. Dead fishes neither rose nor settled. The pH of the water increased to between 8.2 and 8.9. As compared to the 96-hr. $TL_m$ (160 p.p.m.), 18, 100, 200, and 500 p.p.m. killed or injured goldfishes, carp, bass, or "fishes" (13) (27) (28).

**Calcium sulfate**—$CaSO_4$: At 56,000 p.p.m. two fishes were dead at 24 hr. and the remaining eight were normal at 96 hr. No other deaths occurred. At 56,000 and 32,000 p.p.m. turbidity was precipitated in 24 hr. At the lower concentrations the fishes showed no effect. As compared to the 96-hr. $TL_m$ (> 56,000 p.p.m.), 633 p.p.m. was toxic to Japanese oysters (22).

**Carbon disulfide**—$CS_2$: All fishes were normal in less than 100 p.p.m. At 180 p.p.m. all were near the surface at 24 hr. and all were dead in 48 hr. At the higher concentrations all were dead in 24 hr. There was no effect on turbidity. As compared to the 96-hr. $TL_m$ (135 p.p.m.), Shelford (35) reported 100 to 127 p.p.m. killed *Lepomis humilis* in 1 hr. and 5,000 p.p.m. killed trout.

**Copper sulfate**—$CuSO_4$: At 56 p.p.m. two fishes died. At 100 p.p.m. and higher all were killed in 24 hr. At 100 p.p.m. turbidity was reduced; at lower concentrations it was not affected. At 180 p.p.m. and higher turbidity was precipitated. As compared with the 144-hr. $TL_m$ (68 p.p.m.), Turnbull, DeMann and Weston (38) gave 24- and 48-hr. $TL_m$'s for bluegills between 3 and 44 p.p.m.

**Cresol**—$CH_3C_6H_4OH$: Fishes showed noticeable distress at 10 and 18 p.p.m., but all survived at least 72 hr. Two were dead in 18 p.p.m. in 96 hr. and the others showed signs of distress. One was dead in 10 p.p.m. at 96 hr.; the others appeared normal. At 32 p.p.m. and higher all were dead in 24 hr. No special effect was produced on turbidity. As compared with the 96-hr. $TL_m$ (22 p.p.m.), 10 and 13.6 p.p.m. were the 96-hr. $TL_m$'s for bluegills of different sizes (30).

**Cupric oxide**—CuO: No fishes were killed between 10 and 56,000 p.p.m. Turbidity was only slightly changed. The 96-hr. $TL_m$ was greater than 56,000 p.p.m.

**Cyclohexane**—$C_6H_{12}$: All fishes were normal below 10,000 p.p.m. At 24,000 p.p.m. all were dead in 24 hr. No noticeable effects occurred on turbidity. As compared to the 96-hr. $TL_m$ (15,500 p.p.m.), Hubault (24) reported toxicity to fishes at 10 p.p.m. in 3.16 hr.

**Diethanolamine** (2,2-Iminodiethanol)—$NH(CH_2CH_2CH_2)$: At 320 p.p.m. and below all fishes were normal for 96 hr. In 144 hr. five were dead at 560 p.p.m. In three tests an average of one fish was dead in 96 hr. in 1,000 p.p.m.; all were dead in 144 hr. At 1,800 p.p.m. five survived for 24 hr., but died in 48 hr. At higher concentrations all were dead in 24 hr. No drastic changes in turbidity occurred during 144 hr. As compared with the 144-hr. $TL_m$ (560 p.p.m.), Turnbull, DeMann and Weston (38) listed a 24-hr. $TL_m$ of 2,100 p.p.m. and a 48-hr. $TL_m$ of 1,850 p.p.m.

**Diethylene glycol** (2,2-Oxydiethanol)—$(HO \cdot CH_2 \cdot CH_2)_2O$: At 10 to 32,000 p.p.m. the fishes showed no ill effects and all were alive at 96 hr. No significant change was noted in turbidity. The 96-hr. $TL_m$ was greater than 32,000 p.p.m.

**Ferric chloride**—$FeCl_3$: At 56 p.p.m. and below all fishes remained in good condition for 96 hr. At 100 p.p.m. they surfaced immediately and secreted large quantities of mucus. A precipitate formed very rapidly after addition of chemical and fishes. At 24 hr. all fishes were dead and the water was clear. At 56 p.p.m. and less, pH was not much lower (to 6.2) nor was turbidity precipitated. The pH was reduced and then increased during the test period. At 100 p.p.m. pH was lowered to 4 and turbidity was precipitated. As com-

pared to the 96-hr. $TL_m$ (74 p.p.m.), 100 p.p.m. killed goldfishes (14).

**Ferric sulfate**—$Fe_2(SO_4)_3$: At 100 p.p.m. and below all fishes were normal. At 180 p.p.m. and higher all were dead in 24 hr. Considerable mucus was secreted. Turbidity was precipitated in 24 hr. with the higher concentrations, almost precipitated at 100 p.p.m., and not affected at 56 p.p.m. The pH was not significantly affected at 56 p.p.m. or lower, reduced to 6.0 at 100 p.p.m., and reduced to 3.7 at 180 p.p.m. As compared to the 96-hr. $TL_m$ (133 p.p.m.), 0.716 p.p.m. killed shiners, carp and suckers in 12 to 24 hr. (7).

**Ferrous oxide**—FeO: Between 10 and 10,000 p.p.m. the fishes were normal. Only slight changes occurred in turbidity. The 96-hr. $TL_m$ was greater than 10,000 p.p.m.

**Ferrous sulfide**—FeS: All fishes were normal at 10,000 p.p.m. At 3,200 p.p.m. and less there was no effect on turbidity. At 5,600 p.p.m. turbidity was reduced about one-half. At 10,000 p.p.m. turbidity was reduced to less than one-third in 18 hr. and completely precipitated in three days. The 96-hr. $TL_m$ was greater than 10,000 p.p.m.

**Ferrous sulfite**—$FeSO_3 \cdot 2\frac{1}{2}H_2O$: At 180 p.p.m. and lower all fishes were normal for 96 hr. At 320 p.p.m. four were dead in 24 hr. At 560 p.p.m. all were dead in 24 hr. At 100 p.p.m. turbidity was reduced to less than one-fourth its original concentration. At 180 p.p.m. and higher turbidity was precipitated in 24 hr. The pH was not affected at 100 p.p.m. and lower, and not significantly reduced at 180 p.p.m. At 320 p.p.m. the pH was reduced from 7.0 to between 5.1 and 6.0; at 560 p.p.m. to between 3.4 and 3.6. The 96-hr. $TL_m$ was 350 p.p.m.

**Furfural**—$C_4H_3OCHO$: At 10 p.p.m. all fishes were normal. At 18 p.p.m. nine seemed normal at 144 hr., but one was dead at 48 hr. At 32 p.p.m. all were normal at 24 hr., but all were dead at 48 hr. At 56 and 100 p.p.m. all were dead in 24 hr. Some reduction of turbidity was noted at 56 p.p.m.; a definite reduction at 100 p.p.m. As compared to the 96-hr. $TL_m$ (24 p.p.m.), a 24-hr. $TL_m$ for bluegills was between 25 and 32 p.p.m. and a 48-hr. $TL_m$ was 16 to 17 p.p.m. (38).

**Heptane**—$CH_3(CH_2)_5CH_3$: At 5,600 p.p.m. and below all fishes appeared normal. At 10,000 p.p.m. all were dead in 24 hr. Turbidity was not affected at 5,600 p.p.m. and lower. At 10,000 p.p.m. turbidity was reduced to approximately one-fourth of original concentration. As compared with the 96-hr. $TL_m$ (4,924 p.p.m.), Hubault (23) found that 30 p.p.m. of *n*-heptane killed white roach in 1 to 4 hr.

**Hydrochloric acid**—HCl: At 180 p.p.m. and lower there was no noticeable effect. At 320 p.p.m. and higher all fishes were dead in 1½ hr. At 320 p.p.m. and higher turbidity precipitated immediately to less than 25 p.p.m. As compared with the 96-hr. $TL_m$ (282 p.p.m.), various concentrations are listed as lethal, ranging between 3.6 p.p.m. for the green sunfish in 48 hr. and 200 p.p.m. (37)(41)(42). Ellis (14) stated that 157 p.p.m. in hard water did not injure goldfish in over 100 hr.

**Lead nitrate**—$Pb(NO_3)_2$: At 180 p.p.m. and lower all fishes were normal. At 320 p.p.m. and higher all were dead in 24 hr. Turbidity was not affected at 180 p.p.m. and lower. At between 180 and 560 p.p.m. turbidity was gradually reduced to less than 25 p.p.m. At 1,000 p.p.m. turbidity precipitated in 24 hr. The 24- and 48-hr. $TL_m$'s for the red shiner (*Notropis lutrensis*) were both 630 p.p.m. As compared to the 96-hr. $TL_m$ for *Gambusia* (240 p.p.m.), 24- and 48-hr. $TL_m$'s were 6.3 p.p.m. (38).

**Lead oxide**—PbO: At 56,000 p.p.m. one fish was dead in 24 hr., but no other fish seemed to be affected. There was no significant effect on turbidity. The 96-hr. $TL_m$ was greater than 56,000 p.p.m.

**Magnesium chloride**—$MgCl_2$: At 10,000 p.p.m. and below no fishes were killed; however, at 10,000 p.p.m. there was some obvious distress and production of excess mucus. At 24,000 p.p.m. seven were dead in 24 hr., and the others showed signs of distress. One other was dead at 96 hr. while the two remaining fishes were apparently normal. At 32,000 and 56,000 p.p.m. all were dead in 5 hr. Turbidity was not affected below 5,600 p.p.m.; was greatly reduced at 10,000 p.p.m., and completely precipitated in 5 hr. at higher concentrations. As compared with the 96-hr. $TL_m$ (16,500 p.p.m.), goldfishes were killed in 3 to 21 days at 6,757 p.p.m. (31), while 5,000 p.p.m. in distilled water killed the golden shiner (*Notemigonus crysoleucas*) in 96 hr. (44).

**Magnesium sulfate**—$MgSO_4$: At 10,000 p.p.m. and less all fishes were apparently normal. At 24,000 p.p.m. all were dead in 24 hr. At 32,000 p.p.m. five were dead in 24 hr., another in 48 hr., and another in 96 hr.; three appeared normal at 96 hr. At 56,000 p.p.m. all were dead in 24 hr. Above 24,000 p.p.m. the fishes swam quite erratically and secreted large quantities of mucus before finally dying, mostly in 4 hr. Turbidity was reduced to nearly one-seventh in 56,000 p.p.m., but was never completely precipitated. As compared to the 96-hr. $TL_m$ (15,500 p.p.m.), Young (46) reported that 20,900 to 28,400 p.p.m. in cistern water was lethal in 14

days and 24,500 to 27,500 p.p.m. in well water was lethal to perch in 78 days.

**Maleic anhydride**—$(CHCO)_2O$: At 180 p.p.m. and lower all fishes survived for 96 hr., except for one which died on the last day. At 320 p.p.m. and higher all were dead in 24 hr. At 180 p.p.m. and lower neither turbidity nor pH was changed. In 320 p.p.m. and higher turbidity was precipitated in 24 hr. and pH was reduced. As compared to the 96-hr. $TL_m$ (230 p.p.m.), a 24-hr. $TL_m$ for bluegills was between 150 and 165 p.p.m. and the 48-hr. $TL_m$ was 138 to 145 p.p.m. (38).

**Naphthalene**—$C_{10}H_8$: All fishes appeared normal at 100 p.p.m. and lower. At 180 p.p.m. three were dead in 24 hr. (quite stiff, bodies twisted, mouth gaped open); the remainder seeming near death. At 48 hr. three more were dead; the remaining four in very poor condition. At 72 hr. they appeared to have recovered. At 96 hr. one was dead and the remaining three were removed in apparently good condition. In 320 p.p.m. nine fishes were dead in 24 hr. with distorted bodies, the others dying by 48 hr. At 560 and 1,000 p.p.m. all were dead in 24 hr., with bodies stiff and twisted. Turbidity was not greatly changed. As compared to the 96-hr. $TL_m$ (150 p.p.m.), 4 or 5 p.p.m. killed sunfishes (19)(35) and 40 p.p.m. killed perch (9).

**Nitric acid**—$HNO_3$: The fishes were apparently normal except for signs of nervousness in 56 p.p.m. and below. One died at 56 p.p.m. At 100 p.p.m. all were dead in 24 hr. Turbidity was not significantly reduced. The pH (3.6 to 3.8) was probably critical at 100 p.p.m. and was reduced approximately one unit (to 6.2) at 56 p.p.m. As compared to the 96-hr. $TL_m$ (72 p.p.m.), 750 p.p.m. was lethal for goldfishes (14) and toxicities were between 1.6 and 750 p.p.m. for trout, pickerel, whitefish and goldfish (3).

**Phenol**—$C_6H_6O$: At 32 p.p.m. and less no fishes were killed. At 50 and 56 p.p.m. some were killed, and at 100 p.p.m. all were killed in 24 hr. Dead fishes had their bodies twisted out of shape and reactions apparently due to nervous twitching. This same reaction was noted at 28 and 32 p.p.m. At 18 p.p.m. and below there was no obvious reaction. Turbidity was not especially affected. As compared with the 96-hr. $TL_m$ (56 p.p.m.), the critical range for creek chub was between 10 and 20 p.p.m. (18) and the 24- and 48-hr. $TL_m$'s for bluegill were 19 p.p.m. (38).

**Phosphoric acid**—$H_3PO_4$: At 56 p.p.m. and less all fishes were normal. At 100 p.p.m. all were dead in 24 hr. Large quantities of mucus were secreted before death. Turbidity was precipitated by 24 hr. At 100 p.p.m. the pH was reduced to 4.2 and remained so 24 hr., then gradually rose to normal. The 96-hr. $TL_m$ was 138 p.p.m.

**Potassium chloride**—KCl: All fishes were normal at 560 p.p.m. and below. All were normal during 48 hr. in 1,000 p.p.m. but seven, six and four were killed in 96 hr. on three consecutive tests. Similarly, all were normal for 48 hr. at 1,800 p.p.m., but all were dead at 96 hr. At 3,200 and 5,600 p.p.m. all were normal for 24 hr.; some were dead at 48 hr., and all at 96 hr. At 10,000 p.p.m. five were dead at 24 hr., four others at 48 hr., and all at 96 hr. At 18,000 p.p.m. all were killed in 24 hr. Up to 18,000 p.p.m. no significant change was produced in turbidity. As compared with the 96-hr. $TL_m$ (920 p.p.m.), 74.6 p.p.m. was lethal to goldfishes in distilled water in 15 hr. (31).

**Potassium chromate**—$K_2CrO_4$: In 180 p.p.m. and lower all fishes were normal. At 320 p.p.m. one died at 72 hr. and another was dead at 96 hr. At 560 p.p.m. one was dead at 24 hr., six others at 48 hr., another at 72 hr., and the remaining two at 96 hr. At 1,000 p.p.m. all were dead in 24 hr. Turbidity was not significantly changed. The 96-hr. $TL_m$ was 400 p.p.m.

**Potassium cyanide**—KCN: At 1 p.p.m. all fishes remained normal. At 1.8 p.p.m. they lost equilibrium in a short time and six were dead in 24 hr. At 3.2 p.p.m. and higher all were dead in 24 hr. No noticeable effect on turbidity was noted. As compared to the 96-hr. $TL_m$ (1.6 p.p.m.), the 96-hr. $TL_m$ was 0.45 to 5.7 p.p.m. (30); the 24- and 48-hr. $TL_m$'s for bluegills were 0.28 p.p.m. (38).

**Potassium dichromate**—$K_2Cr_2O_7$: At less than 180 p.p.m. the fishes remained normal. At 320 p.p.m. four were dead at 24 hr., another at 48 hr., and three others at 96 hr. At 560 p.p.m. seven were dead at 24 hr. and another at 96 hr. At 1,000 p.p.m. all were dead in 24 hr. The pH was reduced in all tests (to between 6.1 in 320 p.p.m., and 5.4 in 1,800 p.p.m.). Turbidity was reduced in 1,800 p.p.m., but was not greatly affected in the lower concentrations. As compared with the 144-hr. $TL_m$ with *Gambusia* (140 p.p.m.), a 48-hr. $TL_m$ of 250 p.p.m. was established for *Notropis lutrensis*. Ellis (14) found 100 p.p.m. safe but 500 p.p.m. killed goldfishes, and a 96-hr. $TL_m$ for bluegills was 320 p.p.m. (29).

**Potassium hydroxide**—KOH: All fishes were normal at 56 p.p.m. and less. At 100 p.p.m. seven were dead in 24 hr., another died in 48 hr., and the remaining two seemed normal at 96 hr. The pH was increased (up to 10.3). Turbidity was slightly reduced in 100 p.p.m., but was not affected by lower concentrations. As compared to the 96-hr. $TL_m$ (80 p.p.m.), concentrations of 28.6, 50, 56, and 140 p.p.m. killed fishes (3), but 28 p.p.m.

was harmless to fishes during 10-day exposure (3).

**Potassium nitrate**—$KNO_3$: At 100 p.p.m. and below all fishes were normal. At 180 p.p.m. two were dead at 48 hr., and four more at 96 hr. At 320 p.p.m. one was dead in 24 hr., and all in 48 hr. Below 320 p.p.m. turbidity was not affected; at 560 p.p.m. precipitation occurred in 72 hr., at 1,000 p.p.m. in 24 hr. As compared to the 96-hr. $TL_m$ (162 p.p.m.), 1,203 p.p.m. killed bluegills in 15 days (14).

**Potassium permanganate**—$KMnO_4$: At 10 p.p.m. two fishes were killed in 24 hr. and the remainder were in good condition at the end. At 18 p.p.m. all were dead in 24 hr. A dark brown floc clung to the sides of the fishes until some time after death. When this floc was removed the fishes were pearly white. Dead fishes were straight and stiff. More than 10 p.p.m. caused precipitation of turbidity. As compared to the 96-hr. $TL_m$ for *Gambusia* (12 p.p.m.), a 48-hr. $TL_m$ for the red shiner (*Notropis lutrensis*) and for the orange-spotted sunfish (*Lepomis humilis*) was established at 14 p.p.m. Turnbull, DeMann and Weston (38) reported a 24-hr. $TL_m$ of 4.1 p.p.m. and a 48-hr. $TL_m$ of 3.9 p.p.m. for bluegill.

**Potassium phosphate**—$K_3PO_4$: Less than 560 p.p.m. produced no noticeable effect on the fishes. At 1,000, 1,800, and 3,200 p.p.m. all were dead in 24 hr. The pH was increased (to between 9.13 and 10.04) in 1,000 p.p.m. In 1,800 and 3,200 p.p.m. the pH was 10.79 and 11.32. Turbidity was somewhat reduced at 320 p.p.m., and completely precipitated in 560 p.p.m. and higher. The 96-hr. $TL_m$ was 750 p.p.m.

**Pyridine**—$C_5H_5N$: In 1,000 p.p.m. and less the fishes did not seem to be affected. At 1,800 p.p.m. all were dead in 1⅓ hr. The affected fishes swam erratically and seemed to lose equilibrium after the addition. In 10,000 p.p.m. all were dead in 4 min.; even in 3,200 p.p.m. all were dead in 7 min. As compared to the 96-hr. $TL_m$ (1,300 p.p.m.), 1,477 to 1,576 p.p.m. in tap water killed orange spotted sunfishes in 1 hr. (35) and 1,869 p.p.m. in distilled water killed goldfishes in 10 to 30 hr. (31).

**Refinery effluent**: On one occasion a sample of the effluent from Continental Refining Co. was collected. Three tests were run at between 1 and 10,000 p.p.m. No noticeable effect was produced on the fishes at these concentrations. Neither pH nor turbidity was changed.

**Sodium aluminate**—$NaAlO_2$: At 56 p.p.m. and below there was no effect on the fishes. At 100 p.p.m. one was dead in 48 hr., two others in 96 hr. At 180 p.p.m. four died in 24 hr., four more in 48 hr., and the remaining two in 96 hr. At 320 p.p.m. and higher all were dead in 24 hr. While dying these fishes secreted large quantities of mucus. Turbidity was precipitated in 24 hr. at 18 to 320 p.p.m., but there was no effect at 10 p.p.m. The 96-hr. $TL_m$ was 111 p.p.m.

**Sodium bicarbonate**—$NaHCO_3$: At 5,600 p.p.m. and below all fishes were normal. At 10,000 p.p.m. nine were dead in 24 hr., the other in 48 hr. No significant effect was noted on turbidity. As compared with the 96-hr. $TL_m$ (7,550 p.p.m.), a 96-hr. $TL_m$ for bluegills was between 8,250 and 9,000 p.p.m. (30).

**Sodium bisulfite**—$NaHSO_3$: At 180 p.p.m. and below all fishes were normal. At 320 p.p.m. and higher all were dead in 24 hr. The pH was lowered to 6.4 in 180 p.p.m. and to 2.8 to 3.1 in 320 p.p.m. Turbidity was not affected at 180 p.p.m., but completely precipitated at all higher concentrations. As compared with the 96-hr. $TL_m$ (240 p.p.m.), 145 p.p.m. immobilized *Daphnia* (2).

**Sodium borate**—$Na_2B_4O_7 \cdot 10H_2O$: At 1,800 p.p.m. and lower all fishes were apparently normal. At higher concentrations, unusual results were produced and a very wide spread between the 24-hr. $TL_m$ and 144-hr. $TL_m$ was secured (12,000 and 1,900 p.p.m.) In 3,200 p.p.m. and higher the fishes would usually seem perfectly normal for sometimes as long as 48 hr., then by 96 hr. all would be dead. In some tests continued for 144 hr. at 3,200 p.p.m. fishes were still dying through the 120th hour. No significant change occurred in turbidity in up to 18,000 p.p.m. As compared to the 144-hr. $TL_m$ (1,900 p.p.m.), the toxic threshold for the flatworm (*Polycelis nigra*) was 1,530 p.p.m. (26).

**Sodium carbonate**—$Na_2CO_3$: At 560 p.p.m. and below all fishes were normal for 96 hr. At 1,000 p.p.m. three were dead in 24 hr., four others at 48 hr., and two others at 96 hr. The one remaining was in poor condition at the end of the test. The pH was slightly increased and turbidity remained nearly constant. As compared with the 96-hr. $TL_m$ (740 p.p.m.), a 96-hr. $TL_m$ for bluegills was 300 p.p.m. (30), and the minimum lethal concentration for two species of shiners was 250 p.p.m. (39).

**Sodium chloride**—NaCl: At 15,500 p.p.m. and below the fishes did not seem adversely affected. In 21,000 p.p.m. all were dead in 24 hr. They showed obvious difficulty in maintaining the osmotic pressure within their shrinking bodies. At 21,000 and 24,000 p.p.m. turbidity was precipitated in 24 hr. Turbidity was reduced at 15,500 and 11,500 p.p.m., but not completely precipitated. As compared with the 96-hr. $TL_m$ (17,550 p.p.m.), 14,000 p.p.m. was not lethal to bass and perch in two weeks (4), and perch are

supposed to have survived up to 17,500 p.p.m. for as much as one month (46).

**Sodium chromate**—$Na_2CrO_4$: At 180 p.p.m. and lower all fishes were normal. At 320 p.p.m. one died in 48 hr. and another in 96 hr. At 560 p.p.m. two died in 24 hr., four more in 48 hr. and two others in 96 hr. At 1,000 p.p.m. eight were dead in 24 hr. and all died in 48 hr. Turbidity was not precipitated. As compared with the 96-hr. $TL_m$ (420 p.p.m.), 300 p.p.m. was the $TL_m$ for bluegills (1).

**Sodium dichromate**—$Na_2Cr_2O_7 \cdot 2H_2O$: In 100 p.p.m. and below all fishes were apparently normal. At 180 p.p.m. one was dead in 48 hr. and two more died in 96 hr. In 320 p.p.m. two died in 24 hr., another in 48 hr., two more in 72 hr., another in 96 hr., and still another in 144 hr. At 560 p.p.m. seven died in 24 hr., two others in 96 hr., and all in 144 hr. At 1,000 p.p.m. all were dead in 24 hr. No significant change in the turbidity was recorded. As compared to the 144-hr. $TL_m$ (146 p.p.m.), a 24-hr. $TL_m$ was 500 p.p.m. and 410 p.p.m. was the 48-hr. $TL_m$ for bluegills (38), the toxic limit for bluegills being given as 145 p.p.m. (1).

**Sodium fluoride**—NaF: At 560 p.p.m. and lower all fishes were normal. With 1,000 p.p.m. two were dead in 24 hr., four others in 48 hr. In 1,800 p.p.m. and higher all were dead in 24 hr. Although turbidity was essentially constant at 1,800 p.p.m. and lower, suspended soil was precipitated in 48 hr. at 3,200 p.p.m. and in 24 hr. at the two higher concentrations. As compared to the 96-hr. $TL_m$ (925 p.p.m.), 1,000 p.p.m. killed goldfishes (14).

**Sodium hydrosulfide** (sulfhydrate)—$NaHS \cdot 2H_2O$ and $NaHS \cdot 3H_2O$: The fishes were distressed on transfer but recovered and were normal at 100 p.p.m. and lower. At 180 p.p.m. four were dead in 24 hr. and five more died after almost 144 hr. With 320 p.p.m. seven were dead in 24 hr.; the rest seemed normal to the end. At 560 and 1,000 p.p.m. all died in 24 hr. Turbidity was not lowered. At 100 p.p.m. and higher the pH was gradually lowered (to as much as 3.7). As compared to the 144-hr. $TL_m$ (138 p.p.m.), 4 to 10 p.p.m. was critical for creek chub (18).

**Sodium hydroxide**—NaOH: All fishes were normal at 84 p.p.m. and lower. At 100 p.p.m. one was dead in 24 hr. and another died in 48 hr. At 180 p.p.m. and higher all died in 24 hr. The pH increased to as much as 9.0 in 100 p.p.m. and higher; turbidity was not precipitated. As compared with the 96-hr. $TL_m$ (125 p.p.m.), 43 p.p.m. was the 24-hr. $TL_m$ and 42 p.p.m. the 48-hr. $TL_m$ for bluegills (38); 90 p.p.m. was the maximum tolerance limit for bass and bluegills (17).

**Sodium nitrate**—$NaNO_3$: In 1,800 p.p.m. and lower the fishes remained normal. At 3,200 p.p.m. one died in 72 hr. At 5,600 p.p.m. one was dead in 24 hr., two more in 48 hr., four others in 96 hr. At 10,000 p.p.m. three were dead in 24 hr., five others in 48 hr., and all in 72 hr. In 18,000 p.p.m. all died in 24 hr. The pH was only slightly lowered, turbidity was not precipitated. At compared with the 96-hr. $TL_m$ (6,650 p.p.m.), 9,000 to 10,000 p.p.m. was the 96-hr. $TL_m$ for bluegills (30), and 4,000 p.p.m. killed goldfishes (14).

**Sodium nitrite**—$NaNO_2$: There was no effect on the fishes at 5.6 p.p.m. and lower. At 10 p.p.m. eight were dead in 24 hr., all died in 48 hr. As compared with the 96-hr. $TL_m$ (7.5 p.p.m.), 400 to 2,000 p.p.m. was the critical range for creek chub (18).

**Sodium oxalate**—$Na_2C_2O_4$: At 1,000 p.p.m. and lower, there was no effect on the fishes. At 1,800 p.p.m. and higher all were dead in 24 hr. The turbidity seemed unchanged. As compared to the 96-hr. $TL_m$ (1,350 p.p.m.), 970 p.p.m. was the toxicity threshold for the flatworm (*Polycelis nigra*) (26).

**Sodium phosphate**—$NaH_2PO_4$: All fishes remained essentially normal at 560 p.p.m. and below, but all were dead at 1,000 p.p.m. in 3 hr. Turbidity was reduced at 560 and 1,000 p.p.m. but not completely precipitated. The pH went to 10.5 at 560 p.p.m. and was gradually reduced to 8.4 with no fishes killed. At 1,000 p.p.m. the high pH (11.0) may have been a factor in the death. The 96-hr. $TL_m$ was 720 p.p.m.

**Sodium pyrophosphate** — $Na_4P_2O_7 \cdot 10H_2O$: In 1,000 p.p.m. and lower the fishes survived in good condition. At 1,800 p.p.m. nine were dead in 24 hr.; one survived for 96 hr. In 3,200 p.p.m. and higher all were dead in 24 hr. The pH was increased slightly, but turbidity was not precipitated. The 96-hr. $TL_m$ was 1,380 p.p.m.

**Sodium silicate**—$Na_2SiO_3$: All fishes seemed normal in 1,800 p.p.m. and below. At 3,200 p.p.m. five were dead in 24 hr., the other five in 48 hr. At 5,600 and 10,000 p.p.m. all were dead in 24 hr. Turbidity was not significantly changed. As compared to the 96-hr. $TL_m$ (2,320 p.p.m.), 247 p.p.m. was the 100-hr. toxicity threshold for *Daphnia* (16).

**Sodium sulfate**—$Na_2SO_4$: At 3,200 p.p.m. and below all fishes remained normal. At 5,600 p.p.m. one was dead in 144 hr., at 10,000 p.p.m. one in 48 hr., another in 96 hr., and three more in 144 hr. At 15,500 p.p.m. one was dead in 48 hr., another in 96 hr., all in 144 hr. At 18,000 p.p.m. four died in 24 hr., six in 48 hr., all in 96 hr. At 24,000 p.p.m. five died in 24 hr., nine in 48 hr., all in 96 hr. At 32,000 p.p.m. all were dead in

24 hr. Between 18,000 and 24,000 p.p.m. turbidity was greatly reduced, but not completely precipitated. At 32,000 p.p.m. turbidity was completely removed in 72 hr. As compared to the 144-hr. $TL_m$ (10,000 p.p.m.), the minimum lethal concentration for silver salmon is 16,500 p.p.m. (20), 12,500 to 13,000 p.p.m. is the 96-hr. $TL_m$ for bluegills (30).

**Sodium sulfide**—$Na_2S \cdot 9H_2O$: All fishes were apparently normal at 560 p.p.m. and lower; all died in 24 hr. in 1,000 p.p.m. The pH increased to 10.1 in 560 p.p.m., to 10.5 in 1,000 p.p.m., and reduced (to 8.0) during the test. Turbidity was not significantly changed. As compared to the 96-hr. $TL_m$ (750 p.p.m.), 25 p.p.m. was the 24- and 48-hr. $TL_m$'s for bluegills (38), a minimum lethal concentration was 3.0 to 3.5 p.p.m. for several species of fishes (21).

**Sodium sulfite**—$Na_2SO_3$: All fishes were essentially normal at 1,800 p.p.m. and lower. Eight died in 24 hr. at 3,200 p.p.m., and all in 24 hr. at 5,600 and 10,000 p.p.m. Turbidity was reduced at 3,200 p.p.m., almost completely precipitated at 5,600 and 10,000 p.p.m. As compared to the 96-hr. $TL_m$ (2,600 p.p.m.), 100 p.p.m. killed goldfishes (14).

**Sodium thiosulfate**—$Na_2S_2O_3 \cdot 5H_2O$: All fishes were apparently normal at 21,000 p.p.m. and lower. At 24,000 p.p.m. three were dead in 24 hr., two others in 96 hr. At 32,000 p.p.m. eight were dead at 24 hr., another in 48 hr., all in 96 hr. With 56,000 p.p.m. all died in 24 hr. Turbidity was not significantly reduced at 21,000 p.p.m. and below, but almost precipitated at 24,000 and 32,000 p.p.m. At 56,000 p.p.m. turbidity was precipitated in 24 hr. As compared to the 96-hr. $TL_m$ (24,000 p.p.m.), 5 p.p.m. was the minimum lethal concentration for two species of minnows (39); 2 p.p.m. the maximum tolerance limit for bass and bluegills (17).

**Sodium tribasic phosphate**—$Na_3PO_4$: All fishes were normal at 100 p.p.m. and lower. At 180 p.p.m. three were dead in 24 hr., another in 48 hr., three more in 96 hr. At 320 p.p.m. one was dead in 24 hr., five more in 96 hr. At 560 p.p.m. seven died in 24 hr., the others in 96 hr. At 1,000 p.p.m. all were dead in 24 hr. and the pH increased to 10.3. Turbidity was only reduced in 1,000 p.p.m. As compared to the 96-hr. $TL_m$ (151 p.p.m.), much less than 52 p.p.m. immobilized *Daphnia* (2).

**Sulfur**—S: Up to 10,000 p.p.m. produced no effect on the fishes, pH, or turbidity. As compared to the 96-hr. $TL_m$ (> 10,000 p.p.m.), 16,000 p.p.m. killed goldfishes in 5 hr. (20).

**Sulfuric acid**—$H_2SO_4$: All fishes were normal in 32 p.p.m. and lower; all were dead in 24 hr. in 56 p.p.m. and greater. Turbidity remained constant in 32 p.p.m. and lower, nearly precipitated in 56 and 100 p.p.m., and precipitated at 150 p.p.m. The pH was greatly reduced in 65, 75, 100, and 150 p.p.m. (to as much as 2.7). As compared to the 96-hr. $TL_m$ with *Gambusia* (42 p.p.m.), the 48-hr. $TL_m$ for a river minnow (*Notropis girardi*) was 69 p.p.m. Turnbull, DeMann, and Weston (38) gave the 24- and 48-hr. $TL_m$'s for the bluegill at 49 p.p.m.

**Tannic acid**—$C_{76}H_{52}O_{46}$: At 10 and 18 p.p.m. all fishes were normal. At 32 p.p.m. one was dead after 24 hr., two others at 96 hr. At 56 and 100 p.p.m. all were dead in 24 hr. Only slight change was noted in turbidity. As compared to the 96-hr. $TL_m$ (37 p.p.m.), various authors (3)(14)(34)(43) listed 6.25 to 141 p.p.m. as lethal to several species of fishes.

**Toluene**—$C_6H_5CH_3$: All fishes were normal at 560 p.p.m. and below. At 1,000 p.p.m. two died in 24 hr., another at 48 hr., and another in 96 hr. At 1,800 p.p.m. eight were dead in 24 hr., all in 96 hr. At 3,200 p.p.m. eight were dead in 24 hr., another in 48 hr., the last in 96 hr. At 5,600 and 10,000 p.p.m. all were dead in 24 hr. As compared to the 96-hr. $TL_m$ (1,180 p.p.m.), 22 to over 90 p.p.m. had proved lethal to differing species of fishes (8)(19)(23)(35).

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## MAINTENANCE OF SEWAGE PLANT INSTRUMENTS *

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The problem of instrument maintenance is an important one in the measurement and control of sewage treatment processes. Proper instrumentation can make feasible many processes which could not otherwise be employed (such as flash drying of sewage sludge); it can simplify and improve others (such as continuous-flow separate digestion and the activated sludge process); and, by providing records of sewage flow, gas flow, etc., it can make possible the logical planning of enlargements and new facilities.

These are some of the benefits that modern instrumentation can bring to the sewage treatment profession. The instruments are available and they are not unduly expensive. Yet very few treatment plants have taken proper advantage of these valuable tools.

There are two basic reasons for this lack of application of modern instruments to sewage treatment. First, since many consulting engineers are not well-versed in the field of instrumentation, they tend not to make use of this unfamiliar equipment. Second, such instruments as have been installed in plants have, in general, been inadequately maintained. This has not generated much enthusiasm for any increased use of this tool on the part of operators or engineers. It is with this second phase of the problem that this paper will be concerned.

The problem of instrument maintenance may be approached by considering it in terms of its three constituent elements: personnel, equipment, and techniques. Of these, the most important is personnel. A good instrument repairman can maintain a poor instrument, but a poor repairman will be unable to develop satisfactory techniques to maintain even the best instruments.

### Personnel

*Requirements*

A plant which does not intend to hire and train a good repairman, or contract with some other agency for adequate repair service, should not consider anything other than a very elementary instrumentation system. As most small sewage treatment plants fall into this category, there should be little application of instrumentation in such plants.

This is not true of the larger plants, however, and, in these, the role of the instrument repairman is important. Because of the present competition from private industry (which is more fully aware of the benefits of automation) the recruitment of qualified instrument repairmen for sewage treatment plants is difficult. However, many instrument companies offer free

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service schooling, in their own factories, for customers, and even potential customers. These firms usually offer 2- to 13-week courses which provide excellent opportunities for plant personnel to become adequately trained.

The duties of the repairman require both painstaking attention to detail and the ability to examine problems in their broadest aspects. The ability to assimilate some knowledge of hydraulics, pneumatics, mechanics, and electricity is also required. Because his work encompasses the entire plant, the instrument repairman must be able to get along well with others. Lacking these qualities in the instrument repairman, unsatisfactory maintenance will result. Therefore, it cannot be emphasized too strongly that, before considering the application of instrumentation to sewage treatment, it should definitely be determined that qualified maintenance personnel will be available.

### *Instrument Maintenance at Hyperion*

As an example of the personnel requirements for a large treatment plant, the following information is presented concerning instrument repair work at the Hyperion Treatment Plant in Los Angeles.

The instrument maintenance work at the Hyperion Treatment Plant is accomplished by two repairmen and it is planned to increase this force to three. The work is supervised by the engineering section. The instrumentation system at Hyperion cost approximately $500,000, installed, and includes 300 instruments, 62 automatic control valves, 39 venturi tubes, 22 orifice plates and 27 miscellaneous measuring devices. Simple devices such as manometers, pressure gauges, and thermometers are not included in this summary.

In the Los Angeles area the average salary paid by private industry to instrument repairmen is $454 per month. Table I shows the monthly salaries paid by the City of Los Angeles for comparable and related positions in the Hyperion plant and in the Los Angeles Department of Water and Power.

**TABLE I.—Monthly Salaries of Municipal Instrument Repairmen in Los Angeles, Calif.**

| Job Title | Department | Monthly Salary ($) |
|---|---|---|
| Instrument repairman | Hyperion Plant | 545 |
| Instrument repairman | Water and Power | 488 |
| Water meter repairman | Water and Power | 422 |
| Instrument repair foreman | Water and Power | 565 |
| Water meter repair foreman | Water and Power | 535 |
| Mechanical engineer assistant (instrument supervisor) | Hyperion Plant | 575 |

The policy of paying liberal salaries for these positions has made it possible for the Hyperion plant to recruit excellent men. In fact two of the instrument repairman have been promoted to the class of mechanical engineering assistant, which is the entering level for professional engineering in the city.

### *Instrument Maintenance in Smaller Plants*

It is obvious that smaller plants, with less elaborate instrumentation, will require considerably less maintenance. In some plants, which do not require the services of a full-time instrument repairman, the position could be combined with that of electrician or machinist.

## Equipment

There are, of course, some instruments which are easier to maintain than others, but in general, instruments which look complicated are complicated to service and should not be employed unless adequate maintenance service is available. In addition, the author feels strongly that newly developed instrumentation has no place in most sewage plants but should be well-proven in private industry where service facilities to cope with the inevitable "bugs" are more readily available.

There are some instruments avail-

able which are extremely simple and stable but which have no means of adjustment for high accuracy. An example of such an instrument is the bell-type flow meter with the bell lever connected directly to the indicating mechanism without linkages. With such an arrangement, there is no range adjustment available to correct for any slight errors in manufacture of the parts. The only curve error adjustment that can be made is to add or subtract mercury, and this correction is extremely unpredictable. Thus, minor errors might be present and uncorrectable. On the other hand, the only source of major error is the zero adjustment which is simple to check and correct. With a good maintenance force, this instrument would not be particularly valuable. But if only sketchy maintenance is available, it would be highly desirable.

The following considerations, necessarily general, are offered as a guide in the selection of instrument equipment in relation to the maintenance service which will be available.

*Remote Transmission*

Remote transmission of measurements is usually required and this transmission can be either electric or pneumatic. It is the author's feeling that a pneumatic system is easier to maintain, principally because of the simplicity of the receivers involved. Essentially a pneumatic receiver is merely a pressure gauge while an electric receiver is usually a complete new measuring system. Most automatic controllers are also pneumatic and the final control element, usually a valve, is almost always positioned by an air operator. However, the use of pneumatic transmission is usually limited to distances of 500 to 1,000 ft., while electric transmission is unlimited. There are, therefore, applications for each type.

If pneumatic instrumentation is selected, care must be taken to have available a reliable source of clean, dry, oil-free instrument air. Large plants should have separate air compressors for this purpose, which may have graphite piston rings to obviate lubrication and possible contamination.

*Flow*

If a flow transmitter is used, an instrument should be selected which has an indicating scale actuated by the primary unit (venturi tube, Parshall flume, etc.) and some indication of the transmitter output signal. These provisions are of extreme value in checking and calibrating. If a non-indicating transmitter is used, a separate input manometer and output pressure gauge should be provided.

Venturi tubes measuring raw sludge become coated with grease and sludge and a means for cleaning the interior is required. It is desirable to have the throat section separately flanged for easy removal to provide access to the inlet and recovery cones for cleaning. An inspection opening near the throat is also valuable. If the tubes are large, 6 in. or more in diameter, lifting hooks cast into the concrete walls or ceiling of the adjacent structure are of value in rigging for the removal of the tube from the pipeline.

When measuring sewage or sludge, purging the pressure connections to a venturi tube with water is always a necessity. Where high accuracy is desired, a piezometer ring should be used to average the circumferential pressures in the line. Due to the difficulty of keeping a number of openings clean, however, sludge tubes should have only one pressure connection at the inlet and one at the throat.

A good grade of primary settling tank effluent can be metered successfully using an eccentric orifice plate; that is, one with the hole flush with the pipe invert to allow sediment to be carried through. Such an orifice plate can be supplied at a small fraction of the cost of a venturi tube. The measurement of gas and air can always be accomplished with inexpensive orifice

plates, although there are other considerations such as rangeability and pressure loss which might require positive displacement meters or venturi tubes.

*Temperature*

Temperatures up to about 1,000° F. can be measured by fluid-filled temperature indicators and, if only one or two temperatures are desired, this type should be employed. These instruments are simple and inexpensive but cannot be repaired readily if the connecting capillary tubing is damaged. Specialized instrument repair shops can perform this work but the cost is about 50 per cent of the cost of a new instrument.

If a large number of temperature points are desired, or if the service is unusually heavy, thermocouples are more desirable. The thermocouple wire costs only a few cents per foot and a single indicator (a potentiometer) can be used to indicate or record as many as 24 measurements.

*Level*

There are some instances in a sewage treatment plant where a float-operated level instrument can be used but, whenever rags, debris, or grease can contact the float, trouble will be constant. For most liquid-level measurements of raw sewage or sludge, a water- or air-purge system (which is simply a pressure measurement) is more desirable.

Electrodes are sometimes used for signaling alarms at set levels or actuating pump controls. However, problems of grease, insulation, and debris are always present. A recent development of the City of Los Angeles Bureau of Engineering has been the use of a plastic well attached to a large flexible bladder. The well and bladder are filled full with fresh water and immersed in the sewage, causing the free surface of the fresh water in the well to correspond to the free surface of the sewage. Electrodes placed in the fresh water well can thus operate free from the actual sewage or sludge. This system will be marketed soon by an equipment manufacturer.

*Accuracy*

Accuracy claims by the instrument manufacturers are not all made on the same basis. Some base instrument accuracy on a per cent of reading at any point on the scale and others on a per cent of the full-scale range of the instrument. The latter seems to be more in line with the actual observed capabilities of the instruments.

A good instrument should be able to produce an accuracy of plus or minus 1 per cent of full scale and this, in general, is the allowable error for instruments repaired and calibrated in the instrument shop at the Hyperion Plant. The longer calibrating time necessary to achieve, for example, ½ per cent error is not normally justified, and many instruments can neither attain nor retain such accuracies.

If a field-calibrating check of an operating instrument should reveal an error of 1½ per cent, this does not mean that the instrument should be removed and serviced immediately. As a rule, 2 per cent, 3 per cent and even greater error can often be tolerated. The problem of keeping all instruments always within 1 per cent would prove extremely wasteful of manpower. By the time an error of about 3 per cent or greater has occurred, most instruments will require overhaul for other reasons, such as sluggish response, hysteresis, etc.

## Techniques

No matter how expert the instrument repairman becomes in servicing and repairing the actual mechanisms within the instrument case, this skill alone will not guarantee a successful maintenance program. In general, the most difficult problems to solve lie, not in the instrument proper, but in the application of the instrument system to the process variable being measured or controlled. Some of these problems will be discussed in this section.

*Purge Media Errors*

One of the peculiarities of flow- and liquid-level measurements in a sewage plant is that, usually, the fluid being measured cannot be allowed actually to reach the instrument. Air and water purges are used to preclude this and the actual pressures which reach the flow meter, or level instrument are exerted by these purge media. A common source of error in these cases is that the purge pressure at the instrument does not indicate correctly the pressure in the fluid being measured. In the case of the flow meter, for example, the purge rates may be unequal with a greater purge flow into the upstream tap of the venturi tube. The added friction loss for this greater purge flow will result in a larger pressure differential being reported to the instrument than actually exists in the venturi tube, and the instrument will indicate an erroneously high flow rate. The same type of error could result with equal purge rates if a restriction existed at one of the pressure connections.

These errors can be eliminated by providing sight-flow indicators (rotometers for water, bubbler jars for air) of such sensitivity that inequalities in purge rates can easily be noted and, by adequate maintenance of purge lines, the restrictions may be eliminated. Purge lines should be large, at least ¾-in. pipe, and water purges should be limited to about 0.2 to 0.3 g.p.m.

*Purge System Tests*

A test for proper operation of the purge system is to shut off the purge flow momentarily and verify that the instrument reading does not change. It should also be possible to double the purge-flow rate without appreciably affecting the instrument reading. If the instrument reading does not remain approximately constant during these tests, it is almost certain that a restriction exists in one or both of the purge lines. If high pressure flushing does not eliminate the discrepancy, the lines should be disassembled and cleaned.

*Air and Condensate*

Another common source of error in flow and level meters is the presence of air in liquid instrument lines or water in an air or gas instrument line. To avoid this occurrence, instruments measuring liquid flow should be installed below the pipeline and the connecting piping run on an upward slope to allow air to vent back into the main pipeline. Instruments measuring air or gas flow should be mounted above the pipeline and the connecting piping sloped downward to allow any moisture to drain into the main pipeline. There are, of course, many instances where this is not possible and, in these cases, air vents and moisture drips should be provided at high and low points, and these facilities should receive special attention. These same general precautions should also be observed in the case of liquid-level measurements.

*Raw Sludge Measurement*

One of the biggest problems in the flow measurement of raw sludge is the build-up of a coating on the interior surfaces of the venturi tubes. These surfaces should be cleaned at least once a year and, if the venturi tubes are of large size, the cleaning procedure can represent a major undertaking. In some instances, more frequent cleaning is apparently required. For example, at a plant in Canada, monthly disassembly and cleaning of the 12-in. raw sludge venturi tube is reported.

The ideal solution is to install the tube in a valved by-pass line with blind flanges on each end. Then the sludge flow through the main line need not be stopped when the tube must be cleaned and, by removing the blind flanges, a straight-through cleaning and scraping procedure can be accomplished simply. With this arrangement, frequent cleaning will present no problem. If this piping arrangement is not possible or desirable, the throat section should be

a separately flanged part so that the reduced size and weight of this section will ease the problem of its removal. The inlet and recovery cones can then be cleaned in place.

When these methods are not available, a single bolt can be left in the flanges at each end and the venturi tube rotated on these bolts clear of the line to provide access to the interior. This procedure has been used to advantage to clean a 16-in. raw sludge venturi at the Hyperion plant, and is preferable to removing the venturi tube completely from the line.

Digested sludge does not normally coat the interior of venturi tubes to any great extent and the cleaning procedure described is usually unnecessary. This fact can be used to advantage in checking the performance of raw sludge venturi meters when it is possible to pump through a raw and digested sludge venturi meter in series. Errors in the former which are due to interior coating can then be determined and, if the error is reproducible and not too large, adjustments can be made to the flow instrument to compensate for it. This procedure can extend the time between cleaning the tubes considerably.

*Liquid Level Problems*

Many of the techniques described above are applicable to trouble shooting liquid-level problems. Where air and water purges are required, the same precautions to exclude air in water piping and water in air piping must be observed.

*Air Purge Systems*

When an air purge system is used, the air must be supplied to the purge piping so that there is always a positive flow of air from above the highest possible water level to preclude trapped water in the pressure line leading to the instrument. If the instrument is to be located above this highest water level, the air is merely admitted to the purge line above the liquid surface and no extra piping is involved. However, when the instrument is to be mounted lower than the water surface, as is usual for a digester, the purge line must still be carried to a point above the maximum level and then down to the desired measuring point.

## Conclusions

While many of these factors may seem to be primarily the responsibility of the designer and the instrument company, experience has indicated that many incorrect installations of these instruments have been and will continue to be made. In many cases, if they are to be corrected, it will be up to the operating and maintenance forces to correct them.

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# FUNDAMENTALS OF ANAEROBIC TREATMENT OF ORGANIC WASTES *

By A. M. Buswell

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## Analysis of Pollution Factors

Sewage must be treated to prevent the pollution of streams and the resulting nuisance in the way of odors and the spread of disease. The material in sewage which produces these objectionable results is organic matter, in the form of bacteria, benign and pathogenic, and also in the form of unorganized or dead organic matter.

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Such material is objectionable for four reasons: (a) the pathogenic bacteria spread disease; (b) the dead organic matter serves as food for bacteria, allowing them to multiply under favorable conditions; (c) the organic matter, in decomposing, consumes dissolved oxygen and produces odors; and (d) the organic matter has a very high chlorine demand so that excessive amounts of this disinfectant are required to kill pathogenic bacteria.

This rather complicated analysis of pollution factors can be greatly simplified if the problem is considered from a purely chemical standpoint. Using chemical symbols, the problem can be illustrated very simply. For this purpose it will be considered that all organic matter, living and dead, is composed of carbon, hydrogen, and relatively small amounts of a few other elements which will be represented by X. The symbol for organic matter, then, is written as CHX, and the reaction of this material with sulfate can be written:

$$CHX + SO_4^{2-} \rightarrow CO_2 + H_2S + RHS + OX$$

In other words, the organic matter results in the reduction of sulfates to form the foul-smelling hydrogen sulfide or the even more disagreeable mercaptans, where R stands for any complex organic radical.

## General Purification Reactions

Unoxidized carbon and hydrogen must be removed from the polluted liquor in order to prevent obnoxious conditions and odors. When this has been accomplished, the sewage is purified. It will no longer produce a nuisance, it will have a low or zero chlorine demand, and there will be no further food for bacterial growth. Sewage purification consists essentially of the removal of unoxidized carbon-hydrogen compounds. When reduced to these simple terms, all stabilization processes can be classified under two simple types of reactions, aerobic and anaerobic.

### *Aerobic Process*

The aerobic process can be represented as follows:

$$CHX + O_2 \rightarrow CO_2 + H_2O + OX$$

Complete oxidation of the carbon and hydrogen to carbon dioxide and water (in the case of nitrogen compounds to water and nitrate) would yield an effluent with zero chlorine demand and zero oxygen demand. This process, of course, will be recognized as the one which occurs in either activated sludge tanks or trickling filters. It involves about 30 per cent oxidation or wet burning, and 60 to 70 per cent bioprecipitation (sludge formation).

### *Anaerobic Process*

The second, or anaerobic process, can be represented by the reaction

$$CHX + H_2O \rightarrow CO_2 + CH_4 + X$$

This represents the ideal or complete removal of carbon, partly as the completely oxidized carbon dioxide and partly as methane, which is insoluble and therefore escapes as gas, leaving the liquid purified. This process will be recognized as summarizing what happens in sludge digestion or in the anaerobic fermentation of heavier liquid wastes. Some carbonaceous materials, such as lignin, are resistant to this action and will form a stable humus (digested sludge) amounting in some cases to as much as 50 per cent of the original solid organic matter.

When an industrial waste is very concentrated (containing 1 per cent or more solids, as in the case of distillery, dairy, packinghouse, and other wastes), methane fermentation offers an attractive method of treatment. The operating cost is small, although the original investment is rather large. Altogether, it appears that gas containing 55 per cent methane can be produced from these wastes at $0.05 to $0.10 per 1,000 cu. ft.

*Design of the Digester Fermentation Plant*

An acceptable anaerobic fermentation plant consists of two, or preferably three, tanks with floating covers arranged to operate in series. A heat exchanger is necessary to maintain the desired temperature (about 97° F. for cold wastes and 130° F. for hot wastes). The floating covers are conical, carry domes for gas collection, and are protected by flame traps. The bottoms of the tanks are conical, sloping toward the center. The circulating pumps and piping system must be laid out to provide the following variations in a three-tank system: (a) use of the series in any order; (b) circulation of contents of each tank from bottom or center to center or top; and (c) circulation of the contents of any pair of tanks or all three tanks in a similar manner.

## The Biological Formation of Methane *

*Characteristics of Methane Fermentation*

The methane fermentation is unique in that it may be carried on with the aid of mixed or enriched cultures; hence it is possible to maintain this process on a large scale continuously, for apparently an indefinite period. This is in contrast to many other types of fermentations which require sterile feed and pure culture inoculations.

A second unique characteristic of this fermentation is that with the exception of a few fundamental limitations, such as the necessary mineral salts and ions and the proper carbon-nitrogen ratio, the fermentation can be applied to any type of organic matter. Lignin and mineral oil appear to be the only materials not fermentable and limonene from citrus peel interferes.

The third characteristic is that in a majority of cases the reaction is quantitative, converting the entire substrate to carbon dioxide and methane, according to an empirical equation (1).

Fourthly, no specific temperature limitation is observed. The fermentation can be carried out at temperatures as low as 0° C. and as high as 55° C. The rate at higher temperatures is of course greatly increased. However, once a culture has been acclimated to a given temperature—for example, 26° or 37° C.—a sudden change of as little as one or two degrees may completely interrupt the methane fermentation with the accumulation of acids.

Fifthly, the use of asbestos in certain pure compound culture work on a laboratory scale is sometimes necessary. The presence of inert solid material is equally important in large-scale applications. Addition of straw or sawdust to industrial wastes may be required.

Sixthly, the decomposition of more complicated organic compounds passes through the lower aliphatic acids, characteristically acetic, and they are the immediate precursors of carbon dioxide and methane. It has been observed empirically that if the substrate concentration is too high there is a tendency for these acids to accumulate faster than their conversion into methane occurs. Under this condition, methane formation may be arrested completely. This characteristic of the process is regularly controlled through determination of the amount of volatile acids by a well-known modification of the Duclaux procedure. Empirically it has been found that if the volatile acids rise above 2,000 to 3,000 p.p.m. a condition may develop under which methane fermentation cannot get under way or will be stopped. The addition of alkali does not remedy this situation since it is not a pH effect. It can only be controlled by limiting the amount and rate of addition of substrate. If scum or thick sludge is allowed to accumulate, it will constitute

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a zone of excessive amounts of substrate and will result in the local production of excessive amounts of volatile acids. Adequate circulation prevents these conditions. Mineral salts begin to inhibit the fermentation at 4,000 p.p.m. and 50 p.p.m. of $NO_3N$ inhibits it completely.

*Initiation and Control of the Methane Fermentation*

The design of a plant for treatment of wastes by anaerobic fermentation requires a knowledge of the total volume to be treated per day, the content of organic matter, a sufficient chemical analysis to indicate the carbon to nitrogen ratio, and the presence of necessary mineral salts. The actual pH of the liquor to be treated is not so important as the knowledge of the materials contained therein which may affect the acid concentration during fermentation.

Assuming the proper chemical and physical composition of the waste to be treated, the following rules must be observed:

1. In starting the fermentation, the initial load must not exceed one-tenth of the anticipated final load. This load is increased by 50 to 100 per cent per day with daily determination of volatile acids. If volatile acids begin to increase rapidly the rate of feed must be decreased. The rate of feed which results in a relatively constant volatile acid content below 2,000 p.p.m. is considered a safe continuous load.

2. The temperature selected for the fermentation must be kept constant within $\mp 1°$ or 2° C.

3. To prevent overheated or high concentration zones the tank must be provided with means for circulating from the bottom, middle, and top to the top, middle, and bottom. In other words, complete circulation must be provided for and used. The amount of this circulation usually does not exceed an hour a day in properly operating tanks.

It is preferred to operate this process in a series of three tanks provided with piping for complete inter-circulation, thus avoiding the necessity of dumping a tank which may become sour because of poor operation.

Where the procedures indicated are carefully observed, it has been found possible to load treatment tanks with as much as 16 kg. per cubic meter per day (1 lb. per cu. ft. per day). Without such precautions, the loadings must be kept to one-tenth to one-twentieth of this amount.

And finally, in the author's experience, the process finds its greatest economy in wastes running 1 to 3 per cent digestible solids. Less than 1 per cent solids is likely to result in an undesirably large installation and over 3 per cent solids will usually justify evaporation with the recovery of dry material for either food or fertilizer.

As is no doubt well known, this process is in very general use, and the gas produced is employed either in internal combustion engines for the production of power or, after proper scrubbing, is sold to local gas companies and mixed with regular gas supplies. An extensive bibliography of the process is available (2).

## Recent Work

The developments of the relatively new analytical techniques in chromatography offer simpler and more rapid control procedures. For the volatile acid determination a chromatographic column has been described by Mueller, Buswell, and Larson (3). Further work at the University of Florida has not as yet developed a substitute for the Duclaux as a control method for volatile acids. For research purposes chromatography is invaluable for precise separation and identification of lower fatty acids.

The presentation by Grune, Carter, and Keenan (4) has pointed out the usefulness of chromatography as applied to the gas phase. The method

is giving promising results in fermentation studies at the University of Florida.

The "Pearth" method for scum control, described by Fuhrman (5), depends on gas recirculation. Preliminary reports are highly favorable and several installations now in operation confirm earlier predictions.

High-rate digestion of packing house wastes at Austin, Minn., involved a series of tanks for holding and mixing. Large-scale operating data are not yet available. Continuous anaerobic digestion intended for treatment of the entire flow of small domestic installations has recently been reported by the U. S. Public Health Service, Cincinnati, Ohio (6). It may find application in the industrial field. The design considerations recommended by Mau (7) are likewise applicable to treatment of both sanitary sewage and industrial wastes.


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## INTERESTING EXTRACTS FROM OPERATION REPORTS

"A man must have faith in his work
or he can't work faithfully."—*Anon.*

*Attention operators!* It will be appreciated if copies of all annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

### Annual Report of the Puerto Rico Aqueduct and Sewer Authority for the Fiscal Year 1954–55

BY RAFAEL V. URRUTIA, *Executive Director*

This report marks the end of the first decade of operation of the Puerto Rico Aqueduct and Sewer Authority. In the year 1945, when the Authority was created, only six communities on the Island of Puerto Rico enjoyed 24-hr. water service; 18 per cent of the water supplied received no treatment; and each town and city charged different rates, discriminately applied.

From that chaos emerged the Aqueduct and Sewer Authority, which in 10 years of hard work changed the existing conditions to the point that the revenue bonds of the Authority received ready acceptance and public

officials of other countries studied the Puerto Rico organization.

Today filtered water from 25 filter plants comprises 81.2 per cent of the water production; chlorinated water from 16 partial treatment plants comprises 7.6 per cent; and deep well water makes up the remaining 11.2 per cent. Water is supplied to all of the towns on the island and there are 650 rural communities with piped water supplies. Considerable construction work is under way, both in urban and rural areas.

During the year, sanitary sewer systems were placed in operation in two towns (Ceiba and Aguas Buenas). Now 62 out of the 76 towns provide sanitary sewer service.

Most of the projects are done by force account. The money for the work is obtained from a temporary loan fund, legislative appropriation, and revenue funds. The Authority is in a strong economic condition. Current assets amount to $4,894,459 to meet current liabilities of $2,302,079—a ratio of 2.1 to 1. However, customer deposits of $725,351 are listed with the current liabilities; therefore, for practical purposes the liabilities are only $1,576,728.

Revenues amounted to $6,523,947, an increase of $342,501 over the previous year. Current expenses amounted to $2,989,183, an increase of $152,860. The excess of revenues over current expenses amounted to $3,534,764, and were used as follows:

| Item | Amount ($) |
|---|---|
| Renewal and replacements to the aqueduct and sewer systems (equal to the charge for depreciation) | 795,835 |
| Improvements and extensions | 530,215 |
| Interest payments | 741,258 |
| Bond amortization | 515,000 |
| Bond retirement | 489,510 |
| Miscellaneous debits and credits | −6,187 |
| Subtotal | 3,065,631 |
| Unappropriated net revenue | 469,133 |
| Total | 3,534,764 |

The unappropriated net revenue has been authorized for the use of continued construction of planned urban aqueducts.

**TABLE I.—Sewer Service and Revenue**

| Class | Customers | Revenue ($) |
|---|---|---|
| Residential | 67,888 | 500,083 |
| Commercial | 11,272 | 365,647 |
| Industrial | 505 | 40,037 |
| Temporary service | — | 7,020 |
| Total | 79,665 | 912,787 |

The number of customers for sewer service increased from 71,731 to 79,665, a gain of 7,934 or 9.9 per cent. The revenue from sewer service also increased from $850,855 to $912,787, a gain of 7.3 per cent. Table I summarizes the revenue received and the number of customers for sewer service by class.

*Industrial Wastes*

As industrial development increases, the disposal of industrial wastes presents a problem. A textile dyeing plant in Aguas Buenas has been permitted to connect to the public sewer on an experimental basis. Each request for the disposal of industrial wastes in the public sewers will be studied with a cooperative attitude toward new industry. Adequate pretreatment of industrial wastes will be required when necessary to prevent damage to sewers and upset of treatment plants.

A study of harbor pollution at Mayaguez, in cooperation with Puerto Rican consulting engineers, is being carried out to obtain scientific data concerning existing pollution from domestic and industrial sewage.

*Construction*

Construction of the new metropolitan sewer system will improve existing service in San Juan and provide sewer service to those sections now without it. Cost of the principal trunk sewers and treatment plant will total approximately $26,000,000, of which $11,100,000 will be appropriated by the Commonwealth of Puerto Rico and $400,-

000 will be contributed by the Housing Authority. The municipal governments in the metropolitan area and the property owners will have to contribute as they are benefited.

The initial capacity of the sewage treatment plant is 24 m.g.d., expandable to 60 m.g.d. (Bids were to be accepted early in 1955–56.) During the past year construction was completed and operation initiated on sewage treatment plants in Cabo Rojo, Ceiba, and Aguas Buenas. Nine improvement projects were under way to the sewer systems of various towns.

*Personnel*

The Authority employed 1,097 persons in a variety of jobs. Approximately one-half of the employees took advantage of the training facilities sponsored by the Authority. New employees received adequate guidance.

Electronic timers keep an accurate cumulative record of employee leaves of absence. The system provides a monthly record of the leave used and of the balance remaining to each employee. Leave is classed as annual (vacation) leave, sick leave, maternity leave (half-pay), and military leave.

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# TREATMENT PLANT INSPECTION TRIPS *

By Fred Cooper

*Chief Operator, Sewage Treatment Plant, Pullman, Wash.*

Pullman, Wash., is the home of the State College of Washington. The University of Idaho is only nine miles away. Consequently, the Pullman sewage treatment plant is used by several classes from each school for educational purposes. High school classes and elementary school science classes also visit the plant. In addition, the Boy Scouts and Girl Scouts make annual inspection trips. On several occasions parents have visited the plant after a group of elementary school children had made an inspection. Before the parents leave they explain how they have been paying the sewage assessment but didn't realize that they had been paying for anything like this treatment plant. It is through these groups that the best public relations is obtained.

When the treatment plant was first placed in operation an average of three or four complaints would be received each month on how much the plant was costing the taxpayers. Since landscaping of the grounds with lawns and shrubs has been completed, complaints on costs have ceased. Instead, comments are heard on how beautiful the treatment plant looks. The taxpayers are looking at the plant as a very important asset, rather than a tax burden.

Most of the elementary school classes are interested only in the simple operations and the uses of the various types of equipment. These operations must be explained in a way that can be understood readily. The college chemistry classes are interested primarily in the growth and functions of the trickling filters. All the veterinary students and student nurses make the tour in their junior year. Probably the most interested groups are the engineering classes. A tour with one of the college age groups takes about 2 hr. Some students will come back later to go over the blueprints or to get more information.

To keep the plant in the best condition possible, consistent with effective operation, it is the practice to clean the area in which personnel have worked

* Presented at the 1956 Annual Meeting, Pacific Northwest Sewage and Industrial Wastes Assn., Boise, Idaho; Oct. 4–6, 1956.

immediately after the work is completed. All tools are cleaned and put away promptly. As a result, all areas and tools are always clean, and the tools are where they can be found for the next job. If unexpected guests should drop in the plant is in good condition.

A day's notice is desired when classes are expected, so that the filter distributors and the sides of the tanks, weirs, and channels can be hosed down. After everything outside is cleaned up, the inside units and the buildings are cleaned. A sludge pump can be cleaned constantly; therefore, every effort is made to keep it clean at all times. On the day visitors are expected, the laboratory equipment is set out and samples gathered so that tests can be demonstrated to those interested. Most visitors are interested in the flow charts; accordingly, a few are placed for visitors to study.

The appearance and conduct of plant personnel can also help a lot in selling the idea of sewage treatment. The confidence of the guide in his explanation of the operation and equipment of the plant is important in making the tour an interesting one. An assistant precedes the class and removes any unsightly material from the treatment units. If it happens to be in a tank he hoses it to the other side, out of sight. Occasionally as many as four groups will visit the plant in one day. The same check is made prior to each group to be sure the units are as clean for the last group as for the first.

Before starting an inspection trip, an explanation of the plant layout using a large diagram aids the visitor in orienting himself later. The influent end of the plant is always the starting point, and the trip progresses in the direction of flow through the plant. Legible, weatherproof signs, located at the principal treatment units, are of considerable assistance to the visitor and the guide. With each inspection trip new ideas and improvements can be developed which will increase the value of the inspection and improve public relations.

Public relations may be either positive or negative. A well-operated, clean attractive plant will receive positive benefit from intelligently conducted inspection trips.

## TIPS AND QUIPS

### Dam Sewage Treatment Plant

The roving American, *i.e.*, the tourist, has threatened to pollute the Colorado River as a result of his attraction to Hoover Dam. The Bureau of Reclamation now is constructing a sewage treatment system at the dam.

The need for a sewage treatment plant was not contemplated at the time the dam was built. But as a tourist attraction, the structure draws more than two million visitors per year. Water samples showed contamination below Hoover Dam as far as 60 miles downstream during the summer low flow.

The lesson learned at Hoover Dam has led the bureau to provide for sewage facilities as part of the basic design of Glen Canyon Dam, now under construction several hundred miles upstream.

### Industrial Wastes Posters

In-plant control of industrial wastes can be very effective, but to obtain cooperation from the worker an in-plant public relations program is necessary. Posters can be prepared and used effectively in work areas where the discharge of oil, chemicals, or other materials by an uninformed worker can pollute a stream.

Several effective poster titles to start

an in-plant public relations program are:

When you pour oil down a drain you're hanging a "No Hunting Sign" on all the game land for miles around.

Waste samples poured down the drain can spoil the taste of drinking water of thousands of families.

Take time to stop pollution.

Let's all be good neighbors.

---

## Care of Machinery

Proper maintenance of the vital sewage treatment plant machinery should be performed in a safe manner. The following maintenance procedures, recommended by the National Safety Council, are applicable to most equipment.

*Lubrication*

1. Always stop the machine before cleaning, oiling, or adjusting it.

2. Lock the machine or otherwise make sure that no one can start it while it is being adjusted or repaired.

3. Oil or grease each moving part sufficiently to give it good lubrication, but avoid spills or drips of oil.

4. Clean up any spilled oil or grease immediately.

5. Take advantage of each oiling or greasing to inspect the condition of all visible machine parts; report to the supervisor any unsafe condition at once.

6. Replace all guards immediately after completing each oiling, greasing or other work on the machine.

7. Before starting the machine again, see that all tools that have been used are removed, that all working parts of the machine are free to move without damage, and make sure that no one is in a position to be injured when the machine is set in motion.

*Cleaning Machine Parts*

1. The danger of serious burns when cleaning with motor gasoline is so great that it should never be used for this purpose. Friction, a static spark, an open flame, or a hot surface in the vicinity may easily cause an explosion.

2. Gasoline also will remove the natural oils from the skin, leave it dry, and may cause serious inflammation.

3. Good non-flammable cleaning material may easily be secured. Carbon tetrachloride should be used only for short periods of time under well-ventilated conditions. This liquid is very toxic and can cause death. Gloves should be worn to prevent dermatitis.

4. Sodium carbonate and caustic soda are non-flammable. However, in using them for cleaning purposes the eyes should be protected with suitable goggles; and there is danger of injury to the skin of the hands when strong solutions are used. Observe great care and cleanse the hands and arms thoroughly with soap and hot water.

5. Kerosene is less dangerous than gasoline, because it is not so easily ignited, but there is still serious danger of fire. Avoid letting the clothing become saturated—remove any kerosene soaked garment without delay.

6. Some of the oil companies manufacture solvents having flash-points in excess of 100° F.; these may be used for cleaning purposes at normal temperatures.

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## Effluent Re-Use

Effluent from the Chanute, Kans., sewage treatment works is brought three-quarters of a mile upstream to the water works intake as an emergency measure. It is estimated that 50 to 60 per cent of the water being used by this water-short community of 10,000 can be re-used. The measure has the approval of the Kansas State Board of Health and is credited by city officials as a big factor in keeping the Chanute population supplied with water.

The city's new $400,000 sewage treatment plant reportedly puts out an effluent of better quality than the receiving water. It treats from 600,000 to 800,000 gal. daily. An earth dam at the sewage plant causes effluent to back up to the water intake.

### Suburban Sewage Problems Consolidated

Philadelphia, Pa., got together with its suburbs on an environmental control problem and agreed to accept sewage from two adjacent townships. Under long-term contracts, one for 35 years and the other for 55 years, Lower Merion Township and Upper Darby Township will pay Philadelphia an annual rental fee to discharge into the city system. The townships have to construct connecting lines. Existing facilities of the townships serve a number of other municipalities.

The agreement will have an immediate effect in reducing pollution in the Schuylkill River, one of Philadelphia's water sources.

### Knock Knock!

For a long time the chief operator of the West Frankfort, Ill., sewage treatment plant had put up with knocking and pounding in his large sewage pump. In fact he wondered how the pump stayed together. The pump manufacturer was unable to explain the trouble and none of the remedies suggested eliminated the noise.

The settled sewage at the plant passes through a Parshall flume and drops several feet into the wet well. There is substantial agitation and turbulence of the sewage at this point. After taking another critical look at the entire pumping arrangement, the operator placed a plank in the end of the Parshall flume so that it extended down into the wet well. The plank provided a flow path for the sewage and eliminated much of the turbulence. As a result, entrained air was reduced to a minimum and pump suction was greatly improved. Happily the noise and pounding of the pump was reduced materially.

### Radioactivity Removal

Oxidation ponds can be designed to concentrate, delay, and remove many of the radioisotopes that frequently are found in dilute waste streams. The detention periods of oxidation ponds are relatively long, providing ample opportunity for radioactive decay, coagulation, and sedimentation, incorporation into biological cells, and redilution.

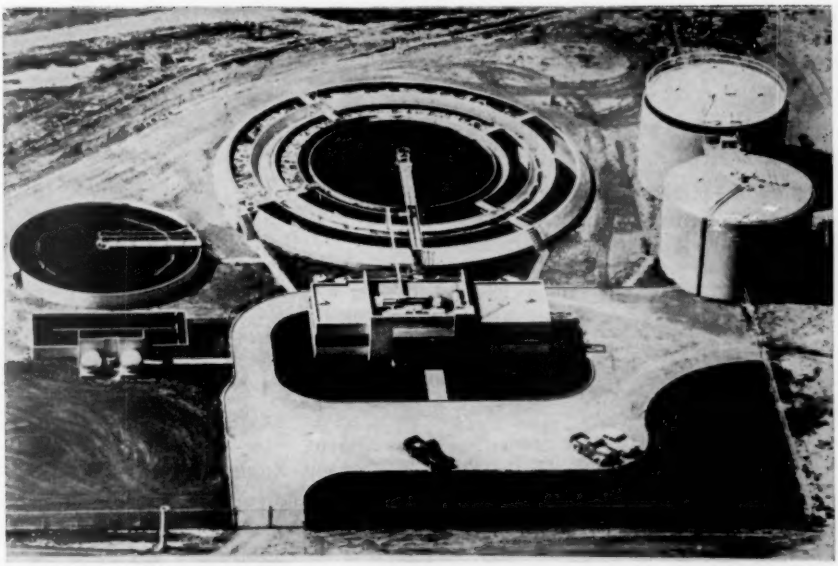
In the case of short-lived radioisotopes, oxidation ponds are ideally suited to detain and dilute radioisotopes. Long-lived radioisotopes present a greater problem, but as a rule most isotopes enter into some chemical or biological reaction whereby the isotope detention is considerably longer than the mean flow through time, resulting in a considerable dilution factor.

### $1 Billion Fire Loss

The National Board of Fire Underwriters reported that the fire loss in the United States would almost reach the $1 billion mark in 1956. This will amount to an increase of 12.2 per cent over the $885 million fire loss for 1955.

This needless waste is equal to the total personal income of New Hampshire, Delaware, Idaho or South Dakota. In addition to the high cost, there is the tremendous suffering and uncounted loss due to the destruction of resources and national wealth. Most appalling of all is the loss of approximately 11,500 lives.

Spring cleanup should be well underway at home and around the sewage treatment plant. Make sure that both will be fire safe. And remember to be extremely cautious when enjoying outdoor fun if your woodlands have been dry!



Engineers—Currie Engineering Company

Photo Credit—Dorr-Oliver

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# Proceedings of Member Associations

## CANADIAN INSTITUTE ON SEWAGE AND SANITATION

The 23rd Annual Convention of the Canadian Institute on Sewage and Sanitation was held in the Prince Edward Hotel, Windsor, Ont., on October 29–31, 1956. A record attendance of 517, including 107 ladies, marked this excellent meeting. The Canadian Institute also took notice of its membership growth to a high of 526.

The technical program featured two guided discussions: one on sewer laying and maintenance practices, and the other on municipal experience with sludge disposal. Papers presented were as follows:

"Industrial Wastes in Public Sewerage Systems," by C. F. Gurnham, Professor, Michigan State University, East Lansing, Mich.

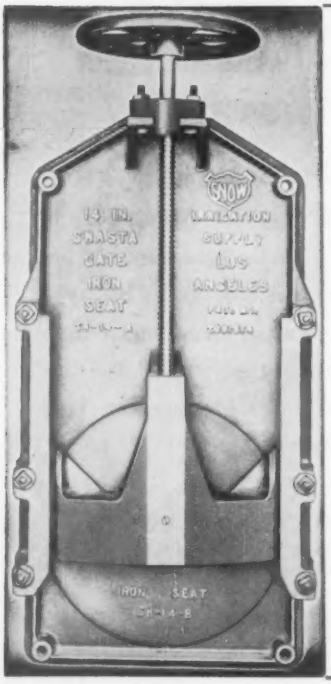
"Air Pollution Studies in the Windsor-Detroit Area and Remedial Measures," by J. R. Menzies, Chief, Public Health Engineering Division, Department of National Health and Welfare, Ottawa, Ont.

"Sewage Oxidation Ponds," by W. W. Towne, J. R. Davis, and A. F. Bartsch, USPHS, Cincinnati, Ohio.

"The Detergent Problem in Sewage Treatment," by James F. MacLaren, Consulting Engineer, Toronto, Ont.

"The Ontario Water Resources and Sewerage Programs," by A. M. Snider, Chairman, Ontario Water Resources Commission, Waterloo, Ont.

(*Continued on page 252a*)

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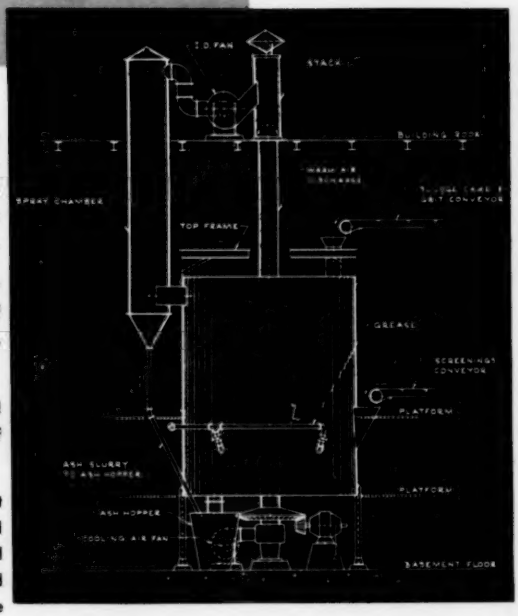


Schematic drawing illustrating the utter simplicity of destroying all sewage organics in a Nichols Herreshoff furnace.

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"A Sewer Plan for the Windsor Area," by N. G. MacDonald, Consulting Engineer, Toronto, Ont., and R. J. Desmarais, Commissioner of Works, Windsor, Ont.

Inspection trips were made to the automobile assembly plant of the Chrysler Corporation of Canada and to the salt mine and processing facilities of the Canadian Salt Company, Ltd. Executive Secretary Ralph E. Fuhrman represented the Federation and presented the Arthur Sidney Bedell Award to Ray J. Desmarais, Commissioner of Works, Windsor, Ont., at the Annual Banquet. The Past President and Twenty-Year Awards also were presented. At the pre-convention gathering Hayse H. Black, USPHS, Cincinnati, Ohio, gave a fine travelogue on his trip to industrial waste treatment plants in Europe.

Officers elected to serve during 1956–57 are:

*President:* L. B. Allan, Toronto, Ont.
*Vice-President:* R. V. Anderson, Toronto, Ont.
*Secretary-Treasurer:* A. E. Berry, Toronto, Ont.

A. E. Berry,
*Secretary-Treasurer*

## PENNSYLVANIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 30th Annual Conference of the Pennsylvania Sewage and Industrial Wastes Association was held at Pennsylvania State University, State College, Pa., on August 29–31, 1956. Approximately 200 members and guests were registered

The technical program featured outstanding papers of interest to sewage and industrial waste treatment personnel. Discussion groups encouraged

(*Continued on page 254a*)

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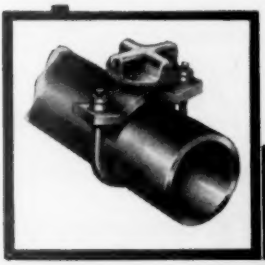

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the active participation of those in attendance.

The Arthur Sidney Bedell Award was presented to Bernard S. Bush, Sanitary Engineer, Pennsylvania State Department of Health, Wilkes-Barre, and former secretary of the Pennsylvania Association. The Hatfield Award was presented to Robert M. Bolenius, Chemist and Chief Operator, Sewage Treatment Plant, Willow Grove. Past President David B. Lee did the honors on behalf of the Federation.

Officers elected for 1956–57 were as follows:

*President:* George A. Elias, Philadelphia.
*First Vice-President:* Bernard S. Bush, Wilkes-Barre.
*Second Vice-President:* Harry W. McElhaney, Meadville.
*Secretary-Treasurer:* J. R. Harvey, Meadville.

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## NEBRASKA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 5th Annual Meeting of the Nebraska Sewage and Industrial Wastes Association was held at Omaha, Nebr., on November 1–2, 1956. A total of 104 persons was registered. A program of particular interest was presented to sewage works operators. Featured were topics on equipment and treatment plant operation.

Officers elected were as follows:

*President:* V. H. Black, Omaha.
*Vice-President:* Lloyd Thomas, Grand Island.
*Secretary-Treasurer:* V. J. Lechtenberg, Omaha.

V. J. Lechtenberg,
*Secretary-Treasurer*

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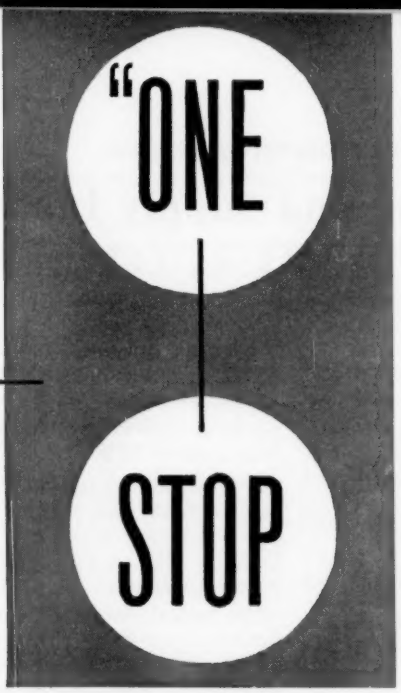


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**Gas Regulators**—Bulletin No. 1059 describes regulators for natural, manufactured and LP gas.—Rockell Manufacturing Co., 400 North Lexington Ave., Pittsburgh 8, Pa.

**Sludge Collector**—Attractively illustrated Bulletin No. 6001-R describes the design and application of the "Monorake" sludge collector for rectangular clarifiers.—Dorr-Oliver Inc., Stamford, Conn.

**Centrifugal Pumps**—Cradle-mounted centrifugal pumps with capacities from 5 to 2,800 g.p.m. are described in Bulletin Form 7223-B.—Cameron Pump Division, Ingersoll-Rand Co., 11 Broadway, New York 4, N. Y.

**Water Hammer**—Manual S presents illustrated material and data on water hammer, cause and control.—Josam Manufacturing Co., Michigan City, Ind.

**Bar Screens**—Back-cleaned bar screens for sewage and industrial waste applications are described in illustrated Bulletin 20S86.—Walker Process Equipment Inc., Aurora, Ill.

**Drain Grates**—A revised brochure presents data on riveted and pressure-locked drain grates.—Irving Subway Grating Co., Inc., Long Island City 1, N. Y.

**Distillation Apparatus**—The scientist interested in fabricating distillation apparatus for research work will appreciate Bulletin FS-256 which describes unitized apparatus of interchangeable parts.—Fisher Scientific Co., 717 Forbes St., Pittsburgh 19, Pa.

**Remote Transmission System**—Bulletin No. 700, a well-documented 16-page reference, describes the application of an electrical system for transmitting flow or other data over a two-wire circuit.—Simplex Valve and Meter Co., 7 East Orange St., Lancaster, Pa.

**Sludge Collectors**—Bulletin No. 315-62 presents specifications and data on conveyor sludge collectors for rectangular clarifiers.—Chain Belt Co., Milwaukee 1, Wis.

**Flocculator-Clarifier Combo**—A combination that makes for smooth flocculation and settling is described in Bulletin No. 6801-R. The Dorreo "Clariflocculator" is a circular unit with central flocculation and circumferential settling. Transfer of floc from one chamber to another without disintegration is claimed as the major advantage of the equipment.—Dorr-Oliver Inc., Barry Pl., Stamford, Conn.

**Pipeline Mixer**—Addendum No. 1, Technical Supplement HM discusses the general theory of mixing and explains the operation of the "Homomix" continuous pipeline (or batch) mixer.—American Well Works, Aurora, Ill.

**Pneumatic Ejectors**—A comprehensive, 28-page illustrated bulletin describes the use and selection of pneumatic ejectors. Bulletin 5408 should be a useful source of information for the engineer or contractor.—R. B. Carter Sales, Inc., 192 Atlantic St., Hackensack, N. J.

**Flowmeter**—The interest in flow meters that provide a smooth bore with no pressure drop continues. A recent addition to the group is the Laub "Electro-Caloric Flowmeter" which reportedly accurately measures and totalizes the mass rate of flow by measuring the rate of heat transfer through the boundary layer of fluid. The unit will also report rate of flow and will measure low and pulsating flows.—Industrial Development Laboratories, Inc., 17 Pollock Ave., Jersey City 5, N. J.

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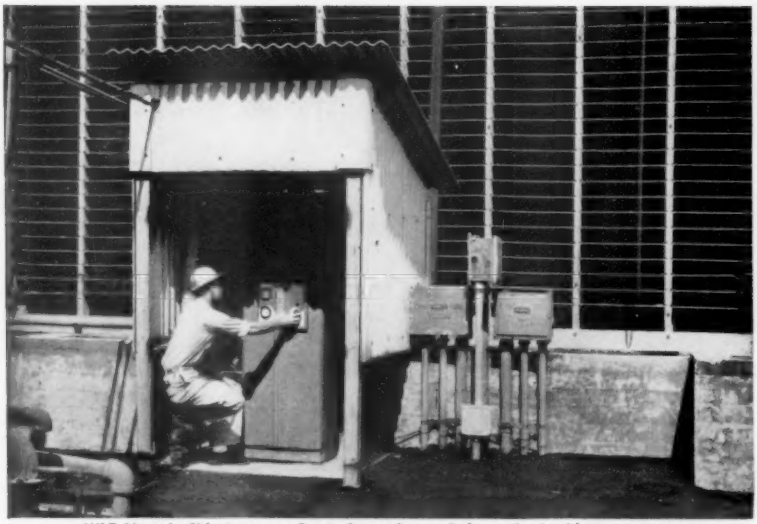

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